AFML-TR-74-250
Part III

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DIELECTRIC CONSTANT AND LOSS DATA

LABORATORY FOR INSULATION RESEARCH
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MASSACHUSETTS 02139

MAY 1977

TECHNICAL REPORT AFML-74-250, Part III
Interim Report for Period July 1974 – January 1977

AIR FORCE MATERIALS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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This technical report has been reviewed and is approved.

John C Olson

JOHN C. OLSON
Project Engineer

FOR THE COMMANDER

Gary L. Denman

GARY L. DENMAN, Actg Chief
Laser Hardened Materials Branch
Electromagnetic Materials Division

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The main body of this report lists dielectric constant and loss data on materials measured in this laboratory in the period 1 July 1974 through 31 December 1976, together with measurements techniques and calculations.

The index following the data section is intended to be a complete reference to dielectric measurement data of this laboratory to date.

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PREFACE

The dielectric constant and loss data presented in this report were measured at the Laboratory for Insulation Research of the Massachusetts Institute of Technology, Cambridge, Massachusetts, by W. B. Westphal. This work was performed between 1 July 1974 and 31 December 1976 under Contract F33615-75-C-5020, Project No. 7371, Task No. 73710126, for the Air Force Materials Laboratory.

A technical report dated December 1975 presents data on materials measured in the early part of this contract. This final report includes data measured through December 31, 1976. The index following the data section refers to early data reports and uses the prefix 9- for pages of the present report. The data section does not generally include measurements on research samples under development by or for the Air Force Materials Laboratory.

This report was submitted by the author for publication in March 1977.

The work was administered under direction of the AF Materials Laboratory, with Mr. John C. Olson (AFML/LPJ) acting as project engineer.

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MEASUREMENT TECHNIQUES

The basic measurement techniques using bridges, reentrant cavities, standing waves, and dielectric-filled cavities have been discussed in previous reports.* During the present contract period we have used new measurement techniques as follows:

1. The use of large (> 1-inch diam.) silver-coated cylindrical specimens contained in copper sheath immersed in an oil bath instead of an air oven. Uniform temperature makes possible resolution to better than 0.01% for determination of temperature coefficient of dielectric constant. The absolute accuracy is limited to about 0.1% by uncertainties in the iris correction. Examples of these measurements are shown on pages 12 and 19 of AFML-TR-74-250, Pt. II.

2. The use of a thin coax washer in the center of a dielectric-filled coax sandwich cavity. In the data reported herein for Corning Glasses 7052 and 7056, two coaxial caps of Dynasil 4000 completed the symmetrical package. Losses were measureable through the softening point, but dielectric constant calculations had not been developed at the time of these runs.

3. The use of a thin (< 1-mm) disk sample to extend the loss range for TE cavities. The data on Niberlox in the present report was obtained with this arrangement.

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* Tech. Rep. 182, Lab. Ins. Res., Contract AF33(616)-8353, October 1963; Tech. Rep. 201, Lab. Ins. Res., Contract AF33(616)-8353, October 1966; AFML-TR-66-28, Lab. Ins. Res., Contract AF33(615)-2199, January 1966; AF ML-TR-70-138, Lab. Ins. Res., Contract F33615-67C-1612, July 1970. AFML-TR-71-66, Lab. Ins. Res., Contract F33615-70C-1220, April 1971; AFML-TR-74-250, Part II, Lab. Ins. Res., Contract F33615-71-C-1274, December 1975.

4. The use of sandwich cavities with thick samples to increase the loss range. For the sample of AS-3DX-176 of woven silica fibers, the usual pressure welding technique for forming the platinum cavity was not advisable. Instead end caps of Dynasil 4000 were added and the welding done at 1000°C in a drill press instead of the usual hydraulic pressing at 800°C.

5. The use of higher order modes in dielectric-filled cavities to reduce the necessity for very small samples and high wall losses at high frequencies. The Dynasil 4000 measurements at 8.5 GHz with one-inch diameter sample (Pt foil) and at 35 GHz with a 0.4" diam. sample (Pt6-Rh.4 foil) used TE 113 or higher order modes. The length, diameter, and mode are chosen to avoid other resonances within 10% frequency range. This scheme is feasible only with homogeneous isotropic materials.

EQUIPMENT CHANGES
(provided by another contract)

An internal doubler for our Hewlett-Packard Model 8640B signal generator extends the range to 1024 MHz. Commercial crystal controlled multiplier chains have been purchased:

Frequency	Power output
1.686	100 mW
2.45	1 W
3	200 mW
8.515	20 mW
13.6117	315 mW

A tripler for the 13.6 GHz unit provides 150 mW output at 40.8 GHz. Beginning in 1977 no funds are available for equipment purchases from the present source.

FUTURE WORK

Construction of standing-wave equipment for 40 GHz is planned. The sample diameter will be 7/32" nominal. The probe carriage, standing-wave and input plunger section will be water-cooled. Operation to 1500°C should be practical on materials which become at least moderately lossy (tan δ > .002) at 1200°C. The empty holder loss measurements will include the effects of ionized gases, which have not yet been evaluated.

PROGRAMMING

Program 1 allows us to scan the possibilities for resonance with dielectric-filled cavities using a specified dielectric constant (K1), diameter (D), frequency in GHz (FGHZ), resistivity of the walls relative to copper (RESRA). For each combination of D and K1 the required length (LENGTH) in cm and the wall loss (1/Q for a no-loss dielectric) is calculated.

An integer variable (X) is used to specify the cross section mode according to the following tabulation:

Value of X	Mode	Value of X	Mode
1	TE11	13	TM21
2	21	14	02
3	01	15	31
4	31	101	TM010, L = 0.1 cm
5	41	102	" , L = 3 cm
6	12	103	" , L = 1 cm
7	51	104	" , L = 3 cm
11	TM01		
12	11		

A second integer variable (N) determines the length mode, except for the TM010 mode where four values of length are given in the program.

Program 2 is used for symmetrical sandwich cavities with TE modes. The

thickness of the end disks must be calculated to achieve resonance at the desired frequency. Also, the dilution effect on losses should be calculated so the proper ratio of sample loss to overall loss can be chosen. In Program 2 only the lengths for resonance are calculated; this program will be later expanded to compute overall loss. In the present printout the following are listed:

F	Frequency for resonance in GHz
K1	Dielectric constant of end cap material
TAN1	Loss tangent
K2	Sample dielectric constant
TAN2	Loss tangent of sample
D2	Thickness of sample in cm
D1	Thickness of each end cap for resonance
D1A	Thickness of end cap to form a cavity one wavelength longer

Program 3 is used to compute the properties of the sample when a coaxial wavemeter is used to measure wavelength (WLM = WL*2) and width of resonance (DELWL). The program uses iteration to refine initial approximate values of K2 and TAN2 to final values calculated with an accuracy of better than one part in a million.

Program 4 computes the dielectric constant and loss of the sample not centered in a coaxial cavity having wall losses determined by measurement of empty cavity. This is especially useful for measuring low-loss materials to about 1 microradian in the 150 to 500 MHz region.

Program 5 is a modified version of Program 2 of Ref. 6. This is used for calculating the attenuation and phase shift of each layer of a multilayer radome (to 10 layers) with perpendicular incidence and now includes calculation of the overall insertion loss.

Each program is written for FORTRAN G and is listed in the Appendix to this section.

Program 1. Resonant Modes and Losses in Dielectric-Filled Cavities

```
FORTRAN IV G1  RELEASE 2.0          DATE = 77011          11/26/27

      INTEGER*4 I,II,J,K,L,N,X,ND,NN,NK,NX,M
      REAL*8 WL,FGHZ,A,PII,PII2,D,C,K1,Y,B,LENGTH,LEIN,P,ND8,TANW,
     2SKIND,RESRA,DIA,ONE,TWO,XN,R
      DIMENSION DATE(39),K1(10),X(20),D(4),N(5)
      NAMELIST/IN/X,D,N,K1,NX,ND,NK,NN,FGHZ,RESRA/OUT/FGHZ,RESRA,SKIND
  200 FORMAT(1X,39A2)
  201 FORMAT(1H0,10X,39A2,/)
  100 FORMAT(2X,2X,1HX,2X,1HN,3X,8HDIA., CM,4X,3H1/Q,8X,9HLENGTH CM,
     25X,11HLENGTH INCH,4X,1HK)
  101 FORMAT(1X,I4,1X,I2,1X,F9.4,1X,F12.9,1X,
     2F12.5,1X,F12.5,1X,F10.5)
   77 READ(5,200,END=88) DATE
      WRITE(6,201) DATE
      READ(5,IN)
      WRITE(6,100)
      PII=3.1415926536D0
      PII2=2.D0*PII
      ONE=1.D0
      TWO=2.D0
      WL=2.99792456201/FGHZ
      SKIND=ONE/(PII2*DSQRT(FGHZ*5.735D5*ONE/RESRA))
      M=0
      DO 10 I=1,NX
      IF(X(I).EQ.1) GO TO 21
      IF(X(I).EQ.2) GO TO 31
      IF(X(I).EQ.3) GO TO 41
      IF(X(I).EQ.4) GO TO 51
      IF(X(I).EQ.5) GO TO 51
      IF(X(I).EQ.6) GO TO 71
      IF(X(I).EQ.7) GO TO 81
      IF(X(I).EQ.11) GO TO 121
      IF(X(I).EQ.12) GO TO 122
      IF(X(I).EQ.13) GO TO 123
      IF(X(I).EQ.14) GO TO 124
      IF(X(I).EQ.15) GO TO 125
      IF(X(I).EQ.101) GO TO 301
      IF(X(I).EQ. 02) GO TO 302
      IF(X(I).EQ.103) GO TO 303
      IF(X(I).EQ.104) GO TO 304
   10 CONTINUE
      WRITE(6,OUT)
      GO TO 77
   21 Y=1.8411840D0
      XN=ONE
      GO TO 80
   31 Y=3.0542370D0
      XN=TWO
      GO TO 80
   41 Y=3.8317060D0
      XN=0.D0
      GO TO 80
   51 Y=4.2011890D0
      XN=4.D0
      GO TO 80
   61 Y=5.3175530D0
      XN=4.D0
      GO TO 80
   71 Y=5.3314430D0
      XN=ONE
      GO TO 80
   81 Y=6.4156160D0
      XN=5.D0
      GO TO 80
```

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Program 1 (cont.)

```
 121 Y=2.40482600
     GO TO 91
 122 Y=8.83170600
     GO TO 91
 123 Y=5.13562200
     GO TO 91
 124 Y=5.52007800
     GO TO 91
 125 Y=6.38016200
     GO TO 91
 301 LENGTH=0.1D0
     GO TO 82
 302 LENGTH=0.3D0
     GO TO 82
 303 LENGTH=1.D0
     GO TO 82
 304 LENGTH=3.D0
     GO TO 82
  80 DO 12 K=1,ND
     A=Y/(PII*D(K))
     DO 16 II=1,NK
     C=K1(II)/WL**2
     B=C-A**2
     IF(B.LE.1.D-2) GO TO 16
     DO 14 L=1,NN
     NDB=N(L)
     LENGTH=0.5D0*NDB/DSQRT(B)
     LEIN=LENGTH/2.54D0
     P=NDB*PII/TWO
     R=D(K)/LENGTH
     TANW=(SKIND/WL)*PII2*(Y**2+(P**2)*R**3+(ONE-R*(P*R*XN/Y)**2))/
    2((ONE-(XN/Y)**2)*(Y**2+(P*R)**2)**1.5)
     DIA=D(K)
     WRITE(6,101) X(I),N(L),DIA,TANW,LENGTH,LEIN,K1(II)
  14 CONTINUE
  16 CONTINUE
  12 CONTINUE
     GO TO 10
  91 DO 11 K=1,ND
     A=Y/(PII*D(K))
     DO 17 II=1,NK
     C=K1(II)/WL**2
     B=C-A**2
     IF(B.LE.1.D-2) GO TO 17
     DO 13 L=1,NN
     NDB=N(L)
     LENGTH=0.5D0*NDB/DSQRT(B)
     LEIN=LENGTH/2.54D0
     P=NDB*PII/TWO
     R=D(K)/LENGTH
     TANW=(SKIND/WL)*PII2*(ONE+R)/DSQRT(Y**2+(P*R)**2)
     DIA=D(K)
     WRITE(6,101) X(I),N(L),DIA,TANW,LENGTH,LEIN,K1(II)
  13 CONTINUE
  17 CONTINUE
  11 CONTINUE
     GO TO 10
  82 Y=2.40482600
     LEIN=LENGTH/2.54D0
     DO 18 II=1,NK
     DIA=WL*Y/(PII*DSQRT(K1(II)))
     R=DIA/LENGTH
     TANW=(SKIND/WL)*PII*(TWO+R)/Y
     WRITE(6,101) X(I),N,DIA,TANW,LENGTH,LEIN,K1(II)
  18 CONTINUE
     GO TO 10
  88 CALL EXIT
     END
```

Program 1 (cont.)

Print-Out of the Program

8.5GHZ TE111 TO TE513,TM011 TO TM313,TM010*4L K=3.82,2.88

M	N	DIA., CM	1/Q	LENGTH CM	LENGTH INCH	K
1	1	2.5400	0.000070775	0.98997	0.38975	3.82200
1	2	2.5400	0.000039988	1.97993	0.77950	3.82200
1	3	2.5400	0.000029725	2.96990	1.16925	3.82200
1	1	2.5400	0.000069444	1.18147	0.46515	2.88000
1	2	2.5400	0.000041754	2.36294	0.93029	2.88000
1	3	2.5400	0.000032525	3.54441	1.39544	2.88000
1	1	1.2700	0.000087678	1.61900	0.63740	3.82200
1	2	1.2700	0.000080639	3.23800	1.27480	3.82200
1	3	1.2700	0.000078293	4.85701	1.91221	3.82200
1	1	1.2700	0.000114491	3.59133	1.41391	2.88000
1	2	1.2700	0.000113505	7.18266	2.82782	2.88000
1	3	1.2700	0.000113177	10.77398	4.24173	2.88000
2	1	2.5400	0.000057830	1.24291	0.48933	3.82200
2	2	2.5400	0.000042273	2.48581	0.97867	3.82200
2	3	2.5400	0.000037087	3.72872	1.46800	3.82200
2	1	2.5400	0.000069218	1.70660	0.67189	2.88000
2	2	2.5400	0.000050030	3.41319	1.34378	2.88000
2	3	2.5400	0.000046968	5.11979	2.01566	2.88000
3	1	2.5400	0.000033532	1.79311	0.70595	3.82200
3	2	2.5400	0.000028351	3.58623	1.41190	3.82200
3	3	2.5400	0.000026624	5.37934	2.11785	3.82200
4	1	2.5400	0.000297386	2.83332	1.11548	3.82200
4	2	2.5400	0.000296073	5.66664	2.23096	3.82200
4	3	2.5400	0.000295635	8.49996	3.34644	3.82200
5	1	2.5400	0.000297386	2.83332	1.11548	3.82200
5	2	2.5400	0.000296073	5.66664	2.23096	3.82200
5	3	2.5400	0.000295635	8.49996	3.34644	3.82200
11	1	2.5400	0.000097732	1.07209	0.42208	3.82200
11	2	2.5400	0.000063370	2.14419	0.84417	3.82200
11	3	2.5400	0.000051916	3.21628	1.26625	3.82200
11	1	2.5400	0.000097276	1.32914	0.52328	2.88000
11	2	2.5400	0.000065346	2.65828	1.04657	2.88000
11	3	2.5400	0.000054703	3.98741	1.56985	2.88000
101	0	1.3786	0.000421843	0.10000	0.03937	3.82200
101	0	1.5881	0.000477836	0.10000	0.03937	2.88000
102	0	1.3786	0.000176246	0.30000	0.11811	3.82200
102	0	1.5881	0.000194910	0.30000	0.11811	2.88000
103	0	1.3786	0.000090286	1.00000	0.39370	3.82200
103	0	1.5881	0.000095886	1.00000	0.39370	2.88000
104	0	1.3786	0.000065727	3.00000	1.18110	3.82200
104	0	1.5881	0.000067593	3.00000	1.18110	2.88000

```
&OUT
FGHZ=  8.5149999999999990    ,FESRA=  1.0000000000000000

SKIND=  .720213229113645994D-04
&END
```

Program 2. Resonant Lengths of Three-Layer Symmetrical TE Cavities

```
      INTEGER *2 I,J,K,N,KOUNT
      REAL*8 PII,ONE,WLC,FR,FG,K2,K2G,K1,K1G,D2,D2G,D1G,TAN1,TAN1G,D1,
     2TAN2,TAN2G,DIA,WL,U,B1,T1,B2,T2,R1,R,ERROR,WE,EROLD,D1OLD,BD,BDA,
     2STEP(14)/1.D-1,1.D-2,3.D-3,1.D-3,3.D-4,1.D-4,3.D-5,1.D-5,3.D-6,
     31.D-6,3.D-7,1.D-7,3.D-8,1.D-8/,F(2)/1.D0,-1.D0/,DIA,PII2
      DIMENSION DATE(39),FG(8),K1G(8),K2G(8),TAN1G(8),TAN2G(8),D2G(8)
      NAMELIST/IN/FG,K1G,K2G,TAN1G,TAN2G,D2G,DIA,N/OUT/WL,U,B1,T1,
     2B2,T2,R,,ERROR/OUT1/D1,T1,R1,R,ERROR
  200 FORMAT(1X,39A2)
  201 FORMAT(1H0,20X,39A2,/)
  100 FORMAT(4X,1HF,7X,2HK1,6X,2HK2,7X,4HTAN1,6X,4HTAN2,7X,2HD2,7X,2HD1,
     28X,3HD1A,4X,4HB1D1,3X,7HTANB2D2,4X,2H11,4X,5HERROR)
  101 FORMAT(1X,F7.3,1X,F7.3,1X,F7.3,1X,F9.5,1X,F9.5,1X,F8.4,1X,F8.4,
     21X,F9.4,1X,F8.4,1X,F8.4,1X,F7.4,1X,E9.4)
   77 READ(5,200,END=88) DATE
      WRITE(6,201) DATE
      READ(5,IN)
      WRITE(6,100)
      PII=3.14159265360D0
      PII2=2.D0*PII
      ONE=1.D0
      WLC=1.706293D0*DIA
      DO 10 I=1,N
      FR=FG(I)
      K2=K2G(I)
      K1=K1G(I)
      D2=D2G(I)
      TAN1=TAN1G(I)
      TAN2=TAN2G(I)
      WL=2.99792456201/FR
      U=(WL/WLC)**2
      B1=PII2*DSQRT((K1-U)*(ONE+DSQRT(ONE+(TAN1/(ONE+U/K1))**2))/2.D0)
     2/WL
      B2=PII2*DSQRT((K2-U)*(ONE+DSQRT(ONE+(TAN2/(ONE+U/K2))**2))/2.D0)
     2/WL
      T2=DTAN(B2*D2)
      R=ONE/T2+DSQRT((ONE/T2)**2+ONE)
      T1=R*DSQRT(K1/K2)
      D1G=DATAN(T1)
      D1=D1G/B1
      R1=T1*DSQRT(K2/K1)
      R=2.D0/(R1-ONE/R1)
      ERROR=DABS(T2-R)
      DO 400 K=1,14
      DO 690 J=1,2
  420 WE=ONE+STEP(K)*F(J)
      KOUNT=0
  401 KOUNT=KOUNT+1
      IF(KOUNT.GT.50) GO TO 449
      EROLD=ERROR
      D1OLD=D1
      D1=D1*WE
      IF(D1.LT.1.D-4) GO TO 449
      T1=DTAN(B1*D1)
      R1=T1*DSQRT(K2/K1)
      R=2.D0/(R1-ONE/R1)
      ERROR=DABS(T2-R)
      IF(ERROR.LE.EROLD) GO TO 401
```

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Program 2 (cont.)

```
      D1=D1OLD
      ERROR=EROLD
  600 CONTINUE
      IF(ERROR.LE.1.D-6) GO TO 450
  400 CONTINUE
      GO TO 450
  449 WRITE(6,OUT1)
  450 BD=B1*D1
      BDA=BD*PII
      D1A=BDA*WL/(DSQRT((K1-U)*(ONE+DSQRT(ONE+(TAN1/(ONE+U/K1))**2))/
     22.D0)*PII2)
      WRITE(6,101) FR,K1,K2,TAN1,TAN2,D2,D1,D1A,BD,T2,T1,ERROR
   10 CONTINUE
      GO TO 77
   88 CALL EXIT
      END
```

Print-Out of the Program

AS3DX 176-17

F	K1	K2	TAN1	TAN2	D2	D1	D1A
8.515	3.823	2.840	0.00015	0.00180	1.9050	0.2219	1.2116
8.600	3.823	2.840	0.00015	0.00180	1.9050	0.2086	1.1866
8.650	3.823	2.840	0.00015	0.00180	1.9050	0.2010	1.1722

B1D1	TANB2D2	T1	ERROR
0.7040	-3.1514	0.7346	.0
0.6701	-2.5596	0.6886	.2220D-15
0.6500	-2.2964	0.6624	.2220D-15

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Program 3. Calculation of Dielectric Properties of Center Section in Three-Layer Symmetrical Cavity

```
      INTEGER*4 I,J,K,N,II,KOUNT,COUNT
      REAL*8 WLM,D1,D2,K1,DIA,TAN1,K2I,TEMP,PII,PII2,ONE,SOLD,
     2STEP(14)/1.D-1,1.D-2,3.D-3,1.D-3,3.D-4,1.D-4,3.D-5,1.D-5,3.D-6,
     31.D-6,3.D-7,1.D-7,3.D-8,1.D-8/,F(2)/1.D0,-1.D0/,WE,K2,TANCAL,
     4T1,B1,WL,A1,U,WLC,K1G,TAN1G,B2,TANM,T2,K2OLD,DELWL,ERROR,EROLD,
     5SILLY(2),WL1,TAHA,TH1R,TH1I,TAN2,A2,TH2R,TH2I,ZB1R,ZB1I,TOLD
      COMPLEX*16 ZONE,ZOONE,ZB1,TWO,A1C,B1C,G1,TH1RC,
     2TH1IC,TH1,A2C,B2C,G2,G12,G21,TH2RC,TH2IC,TH2
      EQUIVALENCE (SILLY(1),ZB1)
      DIMENSION DATE(39),WLM(30),TEMP(30),K1G(30),TAN1G(30),
     2DELWL(30)
      NAMELIST/IN/WLM,TEMP,D1,D2,K1G,TAN1G,K2I,DELWL,N,DIA/OUT/K2,TAN2,
     2TANCAL,ERROR,ZB1R,ZB1I,KOUNT,K,J/OUT1/WL,U,G1,WL1,TH1,G2,TH2,ZB1
  200 FORMAT(1X,39A2)
  201 FORMAT(1H0,20X,39A2,/)
  100 FORMAT(1X,16HWAVELENGTH MEAS.,2X,12HTEMP. DEG. C,4X,2HK1,5X,
     24HTAN1,8X,5HDELWL,4X,2HD1,7X,2HD2,6X,3HDIA,6X,3HK2I)
  101 FORMAT(1X,F9.4,14X,F7.2,1X,F7.3,1X,F9.5,1X,F8.4,1X,F8.4,1X,F8.4,
     1X,F8.4,1X,F8.4)
  102 FORMAT(3X,4HTEMP,9X,4HTANM,8X,4HTAN2,9X,2HK2,9X,4HZB1R,11X,4HZB1I,
     28X,6HTANCAL,5X,5HERROR,7X,1HK)
  103 FORMAT(1X,F7.2,1X,F12.7,1X,F12.7,1X,F12.4,1X,F12.7,1X,F12.7,1X,
     2F12.7,1X,E13.6,1X,I2)
   77 READ(5,200,END=88) DATE
      WRITE(6,201) DATE
      READ(5 IN)
      WRITE(6,100)
      DO 8 II=1,N
      WRITE(6,101) WLM(II),TEMP(II),K1G(II),TAN1G(II),DELWL(II),D1,
     2D2,DIA,K2I
    8 CONTINUE
      ZONE=(1.D0,0.D0)
      ZOONE=(0.D0,1.D0)
      PII=3.1415926536D0
      PII2=6.2831853072D0
      ONE=1.D0
      TWO=2.D0*ZONE
      WLC=1.70629D0*DIA
      K2=K2I
      WRITE(6,102)
      DO 10 I=1,N
      WL=WLM(I)/2.D0
      U=(WL/WLC)**2
      K1=K1G(I)
      TANM=DELWL(I)/(3.D0*WL)-3.D-4*DSQRT(ONE+(TEMP(I)-TEMP(1))*3.8D-3)
      TAN2=TANM*(2.D0*D1+D2)/D2
      TAN1=TAN1G(I)
      B1=PII2*DSQRT((K1-U)*(ONE+DSQRT(ONE+(TAN1/(ONE+U/K1))**2))/2.D0)
     2/WL
      A1=PII2*DSQRT((K1-U)*(-ONE+DSQRT(ONE+(TAN1/(ONE+U/K1))**2))/2.D0)
     2/WL
      T1=DTAN(B1*D1)
      WL1=WL/DSQRT((K1-U)*(ONE+DSQRT(ONE+(TAN1/(ONE+U/K1))**2))/2.D0)
      A1C=ZONE*A1
      B1C=ZOONE*B1
      G1=A1C+B1C
      TAHA=DTANH(A1*D1)
      TH1R=TAHA*(ONE+T1**2)/(ONE+TAHA**2*T1**2)
      TH1I=T1*(ONE-TAHA**2)/(ONE+TAHA**2*T1**2)
      TH1RC=ZONE*TH1R
      TH1IC=ZOONE*TH1I
      TH1=TH1RC+TH1IC
```

Program 3 (cont.)

```
      A2=PII2*DSQRT((K2-U)*(-ONE+DSQRT(ONE+(TAN2/(ONE+U/K2))**2))/2.D0)
     2/WL
      B2=PII2*DSQRT((K2-U)*(ONE+DSQRT(ONE+(TAN2/(ONE+U/K2))**2))/2.D0)
     2/WL
      A2C=ZONE*A2
      B2C=ZOONE*B2
      G2=A2C+B2C
      G12=G1/G2
      G21=G2/G1
      TAHA=DTANH(A2*D2)
      T2=DTAN(B2*D2)
      TH2R=TAHA*(ONE+T2**2)/(ONE+TAHA**2*T2**2)
      TH2I=T2*(ONE-TAHA**2)/(ONE+TAHA**2*T2**2)
      TH2RC=ZONE*TH2R
      TH2IC=ZOONE*TH2I
      TH2=TH2RC+TH2IC
      ZB1=(TWO*TH1+G21*TH2*TH1**2+G12*TH2)/(ZONE+(G21+G12)*TH1*TH2+
     2TH1**2)
      ZB1R=SILLY(1)
      ZB1I=SILLY(2)
      TANCAL=ZB1R*WL1/(PII*(2.D0*D1+D2))
      ERROR=DSQRT((TANCAL-TANM)**2+ZB1I**2)
      COUNT=0
  440 COUNT=COUNT+1
      IF(COUNT GT.3) GO TO 450
      DO 400 K=1,14
      SOLD=STEP(K)
      DO 600 J=1,2
  420 WE=ONE+STEP(K)*F(J)
      KOUNT=0
  401 KOUNT=KOUNT+1
      IF(KOUNT.GT.90) GO TO 450
      IF(KOUNT.GT.10.AND.STEP(K).LE.1.D-3) GO TO 411
      GO TO 425
  411 STEP(K)=STEP(K)*10.D0
      GO TO 420
  425 EROLD=ERROR
      K2OLD=K2
      K2=K2*WE
      B2=PII2*DSQRT((K2-U)*(ONE+DSQRT(ONE+(TAN2/(ONE+U/K2))**2))/2.D0)
     2/WL
      A2=PII2*DSQRT((K2-U)*(-ONE+DSQRT(ONE+(TAN2/(ONE+U/K2))**2))/2.D0)
     2/WL
      A2C=ZONE*A2
      B2C=ZOONE*B2
      G2=A2C+B2C
      G12=G1/G2
      G21=G2/G1
      TAHA=DTANH(A2*D2)
      T2=DTAN(B2*D2)
      TH2R=TAHA*(ONE+T2**2)/(ONE+TAHA**2*T2**2)
      TH2I=T2*(ONE-TAHA**2)/(ONE+TAHA**2*T2**2)
      TH2RC=ZONE*TH2R
      TH2IC=ZOONE*TH2I
      TH2=TH2RC+TH2IC
      ZB1=(TWO*TH1+G21*TH2*TH1**2+G12*TH2)/(ZONE+(G21+G12)*TH1*TH2+
     2TH1**2)
      ZB1R=SILLY(1)
      ZB1I=SILLY(2)
      TANCAL=ZB1R*WL1/(PII*(2.D0*D1+D2))
      ERROR=DSQRT((TANCAL-TANM)**2+ZB1I**2)
      IF(ERROR.LE.EROLD) GO TO 401
      ERROR=EROLD
      K2=K2OLD
```

Program 3 (cont.)


```
      STEP(K)=SOLD
  600 CONTINUE
      DO 700 J=1,2
  421 WE=ONE+STEP(K)*F(J)
      KOUNT=0
  402 KOUNT=KOUNT+1
      IF(KOUNT.GT.90) GO TO 450
      IF(KOUNT.GT.10.AND.STEP(K).LE.1.D-3) GO TO 412
      GO TO 428
  412 STEP(K)=STEP(K)*10.D0
      GO TO 421
  428 TOLD=TAN2
      EROLD=ERROR
      TAN2=TAN2*WE
      B2=PII2*DSQRT((K2-U)*(ONE+DSQRT(ONE+(TAN2/(ONE+U/K2))**2))/2.D0)
     2/WL
      A2=PII2*DSQRT((K2-U)*(-ONE+DSQRT(ONE+(TAN2/(ONE+U/K2))**2))/2.D0)
     2/WL
      A2C=ZONE*A2
      B2C=ZOONE*B2
      G2=A2C+B2C
      G12=G1/G2
      G21=G2/G1
      TAHA=DTANH(A2*D2)
      T2=DTAN(B2*D2)
      TH2R=TAHA*(ONE+T2**2)/(ONE+TAHA**2*T2**2)
      TH2I=T2*(ONE-TAHA**2)/(ONE+TAHA**2*T2**2)
      TH2RC=ZONE*TH2R
      TH2IC=ZOONE*TH2I
      TH2=TH2RC+TH2IC
      ZB1=(TWO*TH1+G21*TH2*TH1**2+G12*TH2)/(ZONE+(G21+G12)*TH1*TH2+
     2TH1**2)
      ZB1R=SILLY(1)
      ZB1I=SILLY(2)
      TANCAL=ZB1R*WL1/(PII*(2.D0*D1+D2))
      ERROR=DSQRT((TANCAL-TANM)**2+ZB1I**2)
      IF(ERROR.LE.EROLD) GO TO 402
      TAN2=TOLD
      ERROR=EROLD
      STEP(K)=SOLD
  700 CONTINUE
      IF(ERROR.LE.1.D-6) GO TO 450
  400 CONTINUE
  450 WRITE(6,103) TEMP(I),TANM,TAN2,K2,ZB1R,ZB1I,TANCAL,ERROR,K
   10 CONTINUE
      GO TO 77
   88 CALL EXIT
      END
```

Print-Out of the Program

AS-3DX 176-17

WAVELENGTH MEAS.	TEMP. DEG. C	K1	TAN1	DELWL
6.9316	25.00	3.823	0.00015	0.0200

D1	D2	DIA	K2I
1.1722	1.905C	2.5400	2.F40C

TEMP	TANM	TAN2	K2	ZB1R
25.00	0.0016236	0.0040740	2.8639	0.0111582

ZB1I	TANCAL	ERROR	K
0.0000006	0.0016236	0.583479D-06	11

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Program 4. Calculation of Dielectric Properties of Sample in Asymmetric Three-Layer Coaxial Cavity

```
0001      INTEGER*4 I,J,K,N,M,KOUNT,COUNT
0002      REAL*8 FS1,FS2,FS,FE1,FE2,FE,QS,QE,C,WLO,DA,DB,SIGR,A1,B1,TAN1,
         2Q1,MV,D1,D2,D3,DT,K2,K22I,TAN2,ONE,TWO,PI1,PI12,Z1,THRB4,WLDAA,
         3TH1T,RZ,TANCAL,TANM,T1,TAMA,TH1R,TH1I,A2,B2,TH2R,TH2I,T3,TH3R,
         4TH3I,ZB1R,ZB1I,ERROR,SOLD,EROLD,K2OLD,WE,TOLD,T2,SILLY(2),DBB,DQ,
         2STEP(14)/1.D-1,1.D-2,3.D-3,1.D-3,3.D-4,1.D-4,3.D-5,1.D-5,3.D-6,
         31.D-6,3.D-7,1.D-7,3.D-8,1.D-8/,F(2)/1.D0,-1.D0/,EXP1,EXPE
0003      COMPLEX*16 ZONE,ZOONE,TWOC,Z1R,Z1I,Z1C,THRB4C,TH1TC,ZSC,ZB1,
         2A1C,B1C,G1,TH1RC,TH1IC,TH1,A2C,B2C,G2,G12,G21,TH2RC,TH2IC,TH2,
         3TH3RC,TH3IC,TH3,THRB3,THRB2,ZB5
0004      EQUIVALENCE (SILLY(1),ZB1)
0005      DIMENSION FE1(10),FE2(10),FS1(10),FS2(10),D1(10),TH(10),
         2DATE(39),M(10),DQ(10)
0006      NAMELIST/CONST/DA,DB,SIGR,EXP1,EXPE/IN/FS1,FS2,FE1,FE2,DQ,TH,M,N
0007  200 FORMAT(1X,39A2)
0008  201 FORMAT(/1H0,20X,39A2/)
0009  101 FORMAT(/1H0,2X,15HFREQ. EMPTY MHZ,12X,19HFREQ. SAMPLE-IN MHZ,10X,
         25HDQ-CM,4X,15HSAMPLE THICK CM,2X,14HNO. HALF WAVES)
0010  102 FORMAT(1H ,F12.6,1X,F12.6,2X,F12.6,1X,F12.6,1X,F12.5,2X,
         2F12.5,12X,I2)
0011  104 FORMAT(/1H0,1X,7HQ-EMPTY,5X,11HQ-THEO.WALL,3X,13HQ-WITH SAMPLE,3X,
         29HDIE-CONST,3X,12HLOSS TANGENT)
0012  105 FORMAT(1H ,F10.4,4X,F10.4,5X,F10.4,2X,F10.5,4X,F12.8)
0013  106 FORMAT(1H0,1X,27HEND LOSS MULTIPLYING FACTOR,1X,
         218HWALL LOSS EXPONENT,1X,17HEND LOSS EXPONENT)
0014  107 FORMAT(1H ,8X,F12.6,8X,F12.6,8X,F12.6)
0015  108 FORMAT(1H0,6X,6HTANCAL,8X,4HTANM,8X,16HCAVITY LENGTH-CM,10X,
         28HEND LOSS)
0016  109 FORMAT(1H ,2X,F12.8,2X,F12.8,4X,F12.5,6X,1H(,E12.6,6X,E12.6,1H))
0017  112 FORMAT(1H0,6X,4HTANM,11X,4HTAN2,7X,9HDIE-CONST,8X,6HZ,REAL,8X,
         27HZ-IMAG.,11X,4HTAN1,6X,5HERROR,10X,1HK)
0018  113 FORMAT(1H ,2X,F12.8,2X,F12.8,2X,F10.5,9X,E12.6,2X,E12.6,2X,F12.8,
         22X,E12.6,2X,I2)
0019   77 READ(5,200,END=88) DATE
0020      WRITE(6,201) DATE
0021      READ(5,IN)
0022      READ(5,CONST)
0023      WRITE(6,101)
0024      DO 20 I=1,N
0025      D1(I)=2.54D0*DQ(I)
0026      D2=2.54D0*TH(I)
0027      WRITE(6,102) FE1(I),FE2(I),FS1(I),FS2(I),D1(I),D2,M(I)
0028   20 CONTINUE
0029      ZONE=(1.D0,0.D0)
0030      ZOONE=(0.D0,1.D0)
0031      PI1=3.14159265360D0
0032      PI12=6.28318530720D0
0033      ONE=1.D0
0034      TWO=2.D0
0035      TWOC=ZONE*TWO
0036      DAA=DA*2.54D0
0037      DBB=DB*2.54D0
0038      C=2.99792456204
0039      DO 10 I=1,N
0040      D2=2.54D0*TH(I)
0041      FE=(FE1(I)+FE2(I))/TWO
0042      FS=(FS1(I)+FS2(I))/TWO
0043      QE=FE/(FE1(I)-FE2(I))
0044      QS=FS/(FS1(I)-FS2(I))
0045      A1=3.47D-7*DSQRT(FE/SIGR)*(TWO/DAA+TWO/DBB)/DLOG(DBB/DAA)
0046      WLO=C/FE
0047      B1=PI12*DSQRT(1.00054D0)/WLO
0048      TAN1=TWO*A1*B1/(B1**2-A1**2)
0049      B1=B1*DSQRT((ONE+DSQRT(ONE+TAN1**2))/TWO)
```

Program 4 (cont.)


```
      TAN1=TWO*A1*B1/(B1**2-A1**2)
      Q1=ONE/TAN1
      MV=M(I)
      DT=MV*PII/B1
      D3=DT-D1(I)-D2
      K2=5.D-1*C*M(I)*(ONE/FS-ONE/FE)/D2+ONE
      K22I=DT*(ONE/QS-ONE/QE)/(TWO*D2)
      TAN2=K22I/K2
      WRITE(6,104)
      WRITE(6,105) QE,Q1,QS,K2,TAN2
      Z1=(ONE/PII2)*DSQRT(2.D-7*PII2/(1.00054*8.854185D-14))*
     2DLOG(DBB/DAA)
      Z1R=ZONE*(Z1*DSIN((PII-TAN1)/TWO))
      Z1I=ZOONE*(Z1*DSIN(TAN1/TWO))
      Z1C=Z1R+Z1I
      THRB4=(ONE/Z1)*DSQRT(PII2**2*FE/(5.808*SIGR))
      THRB4C=ZONE*THRB4
      TH1T=DTANH(A1*DT)
      RZ=(PII*DT/(WL0*QE)-(TH1T+THRB4)/(ONE+TH1T*THRB4))/THRB4
      WRITE(6,106)
      WRITE(6,107) RZ,EXP1,EXPE
      IF(RZ.GT.100.D0) GO TO 77
      TH1TC=ZONE*TH1T
      ZSC=ZONE*(THRB4*RZ)
      ZB1=(TH1TC+THRB4C)/(ZONE+TH1TC*THRB4C)+ZSC
      ZB1R=SILLY(1)
      ZB1I=SILLY(2)
      TANCAL=ZB1R*WL0/(PII*DT)
      TANM=ONE/QE
      WRITE(6,108)
      WRITE(6,109) TANCAL,TANM,DT,ZSC
      WL=C/FS
      TANM=ONE/QS
      THRB4=THRB4*(FS/FE)**EXPE
      THRB4C=ZONE*THRB4
      ZB5=ZONE*(THRB4*RZ)
      A1=A1*(FS/FE)**EXP1
      B1=PII2*DSQRT(1.00054D0)/WL
      TAN1=TWO*A1*B1/(B1**2-A1**2)
      B1=B1*DSQRT((ONE+DSQRT(ONE+TAN1**2))/TWO)
      T1=DTAN(B1*D1(I))
      A1C=ZONE*A1
      B1C=ZOONE*B1
      G1=A1C+B1C
      TAHA=DTANH(A1*D1(I))
      TH1R=TAHA*(ONE+T1**2)/(ONE+TAHA**2*T1**2)
      TH1I=T1*(ONE-TAHA**2)/(ONE+TAHA**2*T1**2)
      TH1RC=ZONE*TH1R
      TH1IC=ZOONE*TH1I
      TH1=TH1RC+TH1IC
      A2=PII2*DSQRT(K2*(-ONE+DSQRT(ONE+TAN2**2))/TWO)/WL
      B2=PII2*DSQRT(K2*(+ONE+DSQRT(ONE+TAN2**2))/TWO)/WL
      A2C=ZONE*A2
      B2C=ZOONE*B2
      G2=A2C+B2C
      G12=G1/G2
      G21=G2/G1
      TAHA=DTANH(A2*D2)
      T2=DTAN(B2*D2)
      TH2R=TAHA*(ONE+T2**2)/(ONE+TAHA**2*T2**2)
      TH2I=T2*(ONE-TAHA**2)/(ONE+TAHA**2*T2**2)
      TH2RC=ZONE*TH2R
      TH2IC=ZOONE*TH2I
      TH2=TH2RC+TH2IC
      T3=DTAN(B1*D3)
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```
      TAHA=DTANH(A1*D3)
      TH3R=TAHA*(ONE+T3**2)/(ONE+TAHA**2*T3**2)
      TH3I=T3*(ONE-TAHA**2)/(ONE+TAHA**2*T3**2)
      TH3RC=ZONE*TH3R
      TH3IC=ZOONE*TH3I
      TH3=TH3RC+TH3IC
      THRB3=G21*(TH3+THRB4C)/(ZONE+TH3*THRB4C)
      THRB2=G12*(TH2+THRB3)/(ZONE+TH2*THRB3)
      Z1R=ZONE*(Z1*DSIN((PII-TAN1)/TWO))
      Z1I=ZOONE*(Z1*DSIN(TAN1/TWO))
      Z1C=Z1R+Z1I
      ZB1=ZB5+(TH1+THRB2)/(ZONE+TH1*THRB2)
      ZB1R=SILLY(1)
      ZB1I=SILLY(2)
      TANCAL=ZB1R*WL/(PII*DT)
      ERROR=DSQRT((TANCAL-TANM)**2+ZB1I**2)
      COUNT=0
  440 COUNT=COUNT+1
      IF(COUNT.GT.3) GO TO 450
      DO 400 K=1,14
      SOLD=STEP(K)
      DO 600 J=1,2
  420 WE=ONE+STEP(K)*F(J)
      KOUNT=0
  401 KOUNT=KOUNT+1
      IF(KOUNT.GT.90) GO TO 450
      IF(KOUNT.GT.10.AND.STEP(K).LE.1.D-3) GO TO 411
      GO TO 425
  411 STEP(K)=STEP(K)*10.D0
      GO TO 420
  425 EROLD=ERROR
      K2OLD=K2
      K2=K2*WE
      A2=PII2*DSQRT(K2*(-ONE+DSQRT(ONE+TAN2**2))/TWO)/WL
      B2=PII2*DSQRT(K2*(+ONE+DSQRT(ONE+TAN2**2))/TWO)/WL
      A2C=ZONE*A2
      B2C=ZOONE*A2
      G2=A2C+B2C
      G12=G1/G2
      G21=G2/G1
      TAHA=DTANH(A2*D2)
      T2=DTAN(B2*D2)
      TH2R=TAHA*(ONE+T2**2)/(ONE+TAHA**2*T2**2)
      TH2I=T2*(ONE-TAHA**2)/(ONE+TAHA**2*T2**2)
      TH2RC=ZONE*TH2R
      TH2IC=ZOONE*TH2I
      TH2=TH2RC+TH2IC
      THRB3=G21*(TH3+THRB4C)/(ZONE+TH3*THRB4C)
      THRB2=G12*(TH2+THRB3)/(ZONE+TH2*THRB3)
      ZB1=ZB5+(TH1+THRB2)/(ZONE+TH1*THRB2)
      ZB1R=SILLY(1)
      ZB1I=SILLY(2)
      TANCAL=ZB1R*WL/(PII*DT)
      ERROR=DSQRT((TANCAL-TANM)**2+ZB1I**2)
      IF(ERROR.LE.EROLD) GO TO 401
      ERROR=EROLD
      K2=K2OLD
      STEP(K)=SOLD
  600 CONTINUE
      DO 700 J=1,2
  421 WE=ONE+STEP(K)*F(J)
      KOUNT=0
  402 KOUNT=KOUNT+1
      IF(KOUNT.GT.90) GO TO 450
      IF(KOUNT.GT.10.AND.STEP(K).LE.1.D-3) GO TO 412
```

Program 4 (cont.)


```
      GO TO 428
  412 STEP(K)=STEP(K)*10.D0
      GO TO 421
  428 TOLD=TAN2
      EROLD=ERROR
      TAN2=TAN2*WE
      A2=PII2*DSQRT(K2*(-ONE+DSQRT(ONE+TAN2**2))/TWO)/WL
      B2=PII2*DSQRT(K2*(+ONE+DSQRT(ONE+TAN2**2))/TWO)/WL
      A2C=ZONE*A2
      B2C=ZOONE*B2
      G2=A2C+B2C
      G12=G1/G2
      G21=G2/G1
      TAHA=DTANH(A2*D2)
      T2=DTAN(B2*D2)
      TH2R=TAHA*(ONE+T2**2)/(ONE+TAHA**2*T2**2)
      TH2I=T2*(ONE-TAHA**2)/(ONE+TAHA**2*T2**2)
      TH2RC=ZONE*TH2R
      TH2IC=ZOONE*TH2I
      TH2=TH2RC+TH2IC
      THRR3=G21*(TH3+THRR4C)/(ZONE+TH3*THRR4C)
      THRR2=G12*(TH2+THRR3)/(ZONE+TH2*THRR3)
      ZB1=Z85+(TH1+THRR2)/(ZONE+TH1*THRR2)
      ZB1R=SILLY(1)
      ZB1I=SILLY(2)
      TANCAL=ZB1R*WL/(PII*DT)
      ERROR=DSQRT((TANCAL-TANM)**2+ZB1I**2)
      IF(ERROR.LE.EROLD) GO TO 402
      TAN2=TOLD
      ERROR=EROLD
      STEP(K)=SOLD
  700 CONTINUE
      IF(ERROR.LE.1.D-6) GO TO 450
  400 CONTINUE
  450 TAN2=TAN2-TAN1
      WRITE(6,112)
      WRITE(6,113) TANM,TAN2,K2,ZB1R,ZB1I,TAN1,ERROR,K
   10 CONTINUE
      GO TO 77
   88 CALL EXIT
      END
```

Print-Out of the Program

```
EICHORN X-DPDA0166,150MHZ,4/9/76  DPD4960,300MHZ,3/10/76  SIGR=.3

FREQ. EMPTY MHZ               FREQ. SAMPLE-IN MHZ           LO-CM
159.907668   159.795774       152.967100   152.855565       44.83100
319.670542   319.472714       301.566003   301.362325       19.86280

                                     SAMPLE THICK CM   NO. HALF WAVES
                                        3.40589               1
                                        4.70357               2

Q-EMPTY     Q-THEO.WALL   Q-WITH SAMPLE   DIE-CONST   LOSS TANGENT
1428.6072    4482.5744      1370.9779      2.24965     0.00016000

END LOSS MULTIPLYING FACTOR WALL LOSS EXPONENT END LOSS EXPONENT
         8.395094                0.500000          0.500000

   TANCAL        TANM         CAVITY LENGTH-CM          END LOSS
 0.00069998    0.00069998        93.74672       (0.669108D-03      0.0

   TANM           TAN2        DIE-CONST          Z,REAL        Z-IMAG.
 0.00072941    0.00002451      2.25698         0.109571D-02  -.689185D-06

                                         TAN1        ERROR          K
                                     0.00022809  0.689185D-06       8
```

Program 5. Attenuation and Insertion Loss and Phase Shift in Multilayer Radome for Perpendicular Incidence

```
      INTEGER*4 I,J,JJ,K,N,KOUNT,M
      REAL*8 T,TA,ALP,BET,K2,PII3,ONE,WL,FAKE(2),A,B,C,D,AB,AA,RB,AR,BR,
     2ERROR1,WE,ROLD,EROLD,AOLD,TAA,TAB,DEN,ABC,ABD,K1,TAN,CDM,SOLD,
     7STEP(22)/1.5D-2,1.2D-2,1.D-2,7.D-3,5.D-3,2.D-3,1.D-3,5.D-4,2.D-4,
     81.D-4,5.D-5,2.D-5,1.D-5,5.D-6,2.D-6,1.D-6,1.D-7,1.D-8,1.D-9,
     91.D-10,1.D-11,1.D-12/,F(2)/1.,-1./,P,DB,EV2,SILLY(2),FUN(2),
     6R,RR,FR,GR,THETA,TGH2A,TG2B,B2,AAA,ZETAM,VSWR,REFL,KEFF,DA,TANEF,
     7EB1R,EB1I,EB12,INSL,FUSS(2)
      COMPLEX*16 ZONE,ZOONE,ALPC,BETC,GAMMA,K1C,K2C,KC,Z0,Z,THRB,RB,
     2TH,ZB,SHGRR,SHGRI,SHGR,SHGI,E,EV,YB,ZETA,EB1,EB,SHGC,SHGRC
      DIMENSION DATE(19),ALP(10),BET(10),GAMMA(10),Z(10),P(11),DBS(10),
     2AR(10),BR(10),RB(10),TH(10),E(11),ZB(11),K1(10),TAN(10),T(10),
     3SHGRC(10),SHGC(10),EB(11)
      EQUIVALENCE (FAKE(1),THRB),(SILLY(1),EV),(FUN(1),YB),(FUSS(1),EB1)
      NAMELIST/IN/K1,TAN,T,N,WL/OUT/GAMMA,Z,ZB/OUT1/A,B,ERROR1,C,
     2D/OUT3/C,D/OUT2/RB,TH,ZB,SHGRR,SHGRI,SHGR,SHGI,A,B,E,THRB,THETR,
     3ERROR1,EB1,EB,SHGC,SHGRC
  202 FORMAT(1H0,23X,9HLAYER NO.,4X,2HK1,6X,9HTAN DELTA,1X,
     212HTHICKNESS,CM,2X,20HACCUMALATIVE LOSS,DB,2X,13HLAYER LOSS,DB,
     32X,16HPHASE SHIFT,DEG.)
  300 FORMAT(28X,I2,2X,F9.5,2X,F11.7,2X,F8.4,10X,F11.7,6X,F11.7,9X,F8.3)
  302 FORMAT(25X,11HINPUT VSWR=,1X,F9.6,4X,20HREFLECTION LOSS, DB=,1X,
     2F8.5)
  303 FORMAT(25X,12HEFFECTIVE K=,1X,F9.6,3X,21HEFFECTIVE TAN DELTA =,
     21X,F10.7)
  201 FORMAT(1H0,20X,19A4)
  200 FORMAT(1X,19A4)
  305 FORMAT(1X,19HINSERTION LOSS, DB=,F11.7)
   77 READ(5,200,END=88) DATE
      WRITE(6,201) DATE
      READ(5,IN)
      PI1=3.14159265360D0
      PI12=6.283185307200
      PII3=PII2/WL
      ONE=1.D0
      ZONE=(1.D0,0.D0)
      ZOONE=(0.D0,1.D0)
      Z0=377.D0*ZONE
      DO 10 J=1,N
      TA=DSQRT(ONE+TAN(J)**2)
      ALP(J)=PII3*DSQRT(K1(J)*5.D-1*(TA-ONE))*T(J)
      BET(J)=PII3*DSQRT(K1(J)*5.D-1*(TA+ONE))*T(J)
      ALPC=ZONE*ALP(J)
      BETC=ZOONE*BET(J)
      GAMMA(J)=ALPC+BETC
      K2=K1(J)*TAN(J)
      K2C=ZOONE*K2
      K1C=K1(J)*ZONE
      KC=K1C+K2C
      Z(J)=Z0/CDSQRT(KC)
   10 CONTINUE
      SUM=0.D0
      E(1)=ZONE
      P(1)=ONE/377.D0
      Z(N+1)=Z0
      ZB(1)=Z0
      THRB=Z0/Z(1)
      WRITE(6,202)
      DO 13 J=1,4
      C=FAKE(1)
      D=FAKE(2)
      R=DSQRT(C**2+D**2)
      IF(R .GT. ONE) GO TO 33
```

Program 5 (cont.)

```
      FR=2.D0*R/(ONE+R**2)
      GR=2.D0*R/(ONE-R**2)
      THETA=DATAN(D/C)
      TGH2A=FR*DCOS(THETA)
      TG2B=GR*DSIN(THETA)
      GO TO 34
   33 RR=ONE/R
      FR=2.D0*RR/(ONE+RR**2)
      GR=-2.D0*RR/(ONE-RR**2)
      THETA=DATAN(D/C)
      TGH2A=FR*DCOS(THETA)
      TG2B=GR*DSIN(THETA)
   34 B2=DATAN(TG2B)
      IF(R .GT. ONE) B2=PII+B2
      B=DTAN(0.5D0*B2)
      AAA=0.25D0*DLOG((ONE+TGH2A)/(ONE-TGH2A))
      A=DTANH(AAA)
   50 AB=ONE+(A*B)**2
      ABC=(A*(ONE+B**2)/AB-C)**2
      ABD=(B*(ONE-A**2)/AB-D)**2
      ERROR1=DSQRT(ABC+ABD)
      DO 400 K=1,22
      SOLD=STEP(K)
      DO 600 JJ=1,2
  420 WE=ONE+STEP(K)*F(JJ)
      KOUNT=0
  401 KOUNT=KOUNT+1
  425 BOLD=B
      EROLD=ERROR1
      B=B*WE
      AB=ONE+(A*B)**2
      ABC=(A*(ONE+B**2)/AB-C)**2
      ABD=(B*(ONE-A**2)/AB-D)**2
      ERROR1=DSQRT(ABC+ABD)
      IF(ERROR1.LE.EROLD) GO TO 401
      B=BOLD
      ERROR1=EROLD
      STEP(K)=SOLD
  600 CONTINUE
      DO 700 JJ=1,2
  421 WE=ONE+STEP(K)*F(JJ)
      KOUNT=0
  402 KOUNT=KOUNT+1
  428 AOLD=A
      EROLD=ERROR1
      A=A*WE
      AB=ONE+(A*B)**2
      ABC=(A*(ONE+B**2)/AB-C)**2
      ABD=(B*(ONE-A**2)/AB-D)**2
      ERROR1=DSQRT(ABC+ABD)
      IF(ERROR1.LE.EROLD) GO TO 402
      A=AOLD
      ERROR1=EROLD
      STEP(K)=SOLD
  700 CONTINUE
      IF(ERROR1.LE.1.D-12) GO TO 450
  400 CONTINUE
  450 AR(J)=0.5D0*DLOG((1+A)/(1-A))
      BR(J)=DATAN(B)
      RB(J)=ZONE*AR(J)+ZOONE*BR(J)
      AA=ALP(J)+AR(J)
      RB=RET(J)+RR(J)
      TAA=DTANH(AA)
```

Program 5 (cont.)


```
      TAB=DTAN(BB)
      DEN=ONE+(TAA*TAB)**2
      TH(J)=ZONE*(TAA*(ONE+TAB**2)/DEN)+ZOONE*(TAB*(ONE-TAA**2)/DEN)
      ZB(J+1)=Z(J)*TH(J)
      THRB=ZB(J+1)/Z(J+1)
      SHGRR=ZONE*(DSINH(AA)*DCOS(BB))
      SHGRI=ZOONE*(DCOSH(AA)*DSIN(BB))
      SHGR=ZONE*(DSINH(AR(J))*DCOS(BR(J)))
      SHGI=ZOONE*(DCOSH(AR(J))*DSIN(BR(J)))
      SHGC(J)=SHGR+SHGI
      SHGRC(J)=SHGRR+SHGRI
      E(J+1)=E(J)*(SHGRR+SHGRI)/(SHGR+SHGI)
      YB=ZONE/ZB(J+1)
      EV=E(J+1)
      EV2=SILLY(1)**2+SILLY(2)**2
      P(J+1)=EV2*FUN(1)
      THETR=DATAN(SILLY(2)/SILLY(1))
      IF(SILLY(2) .LT. 0.D0 .AND. SILLY(1) .GT. 0.D0) THETR=THETR+PII2
      IF(SILLY(2) .LT. 0.D0 .AND. SILLY(1) .LT. 0.D0) THETR=THETR+PII
      IF(SILLY(2) .GT. 0.D0 .AND. SILLY(1) .LT. 0.D0) THETR=THETR+PII
      SUM=T(J)+SUM
      X=2.D0*SUM/WL
      Q=0.D0
      IF(X .GT. Q) GO TO 12
      GO TO 14
   12 Q=Q+ONE
      IF(X .GT. Q) GO TO 12
   14 Q=Q-ONE
      THETD=57.2957795D0*THETR+Q*180.D0-360.D0*SUM/WL
      IF(THETD .GT. 180.D0) THETD=THETD-180.D0
      DBS(J)=10.D0*DLOG10(P(J+1)/P(J))
      DB=10.D0*DLOG10(P(J+1)/P(1))
      WRITE(6,300) J,K1(J),TAN(J),T(J),DB,DBS(J),THETD
   13 CONTINUE
      EB(N+1)=ZB(N+1)/(Z0+ZB(N+1))
      DO 15 J=1,N
      M=N+1-J
      EB(M)=EB(M+1)*SHGC(M)/SHGRC(M)
   15 CONTINUE
      EB1=EB(1)
      EB1R=FUSS(1)
      EB1I=FUSS(2)
      EB12=EB1R**2+EB1I**2
      INSL=10.D0*DLOG10(.25D0/EB12)
      WRITE(6,305) INSL
      ZETA=(ZB(N+1)-Z0)/(ZB(N+1)+Z0)
      ZETAM=CDABS(ZETA)
      VSWR=(ONE+ZETAM)/(ONE-ZETAM)
      REFL=10.D0*DLOG10(ONE/(ONE-ZETAM**2))
      WRITE(6,302) VSWR,REFL
      KEFF=(WL*THETD/(360.D0*SUM)+ONE)**2
      DA=38.5903890D0*SUM*DSQRT(KEFF)/(DB*WL)
      TANEF=DSQRT(2.D0/DA**2+ONE/DA**4)
      WRITE(6,303) KEFF,TANEF
      GO TO 77
   88 CALL EXIT
      END
```

Program 5 (cont.)

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Print-Out of the Program

```
ROCKWELL 9-LAYER RADOME  3 GHZ   74 DEG.F.

LAYER NO.    K1        TAN DELTA  THICKNESS,CM  ACCUMALATIVE LOSS,DB
    1      2.44000    0.0068000     0.0530          0.0009846
    2      1.11550    0.0000900     5.0800          0.0023020
    3      3.59000    0.0125000     0.0500          0.0040788
    4      1.21500    0.0033900     0.2640          0.0067270
    5      3.59000    0.0125000     0.0500          0.0086609
    6      4.14000    0.0100000     0.0660          0.0108214
    7      1.12500    0.0027000     1.2280          0.0236838
    8      4.14000    0.0100000     0.0660          0.0262639
    9      1.30400    0.0045300     0.3200          0.0317474

                                 LAYER LOSS,DB  PHASE SHIFT,DEG.
                                   0.0009846        0.001
                                   0.0013174        9.743
                                   0.0017768        9.800
                                   0.0026482       10.382
                                   0.0019339       10.558
                                   0.0021605       10.840
                                   0.0128623       27.576
                                   0.0025801       28.559
                                   0.0054834       32.756

INSERTION LOSS. DB=  0.1499004

   INPUT VSWR=  1.391847    REFLECTION LOSS, DB=  0.11815
   EFFECTIVE K=  1.269634   EFFECTIVE TAN DELTA =  0.0014387
```

DATA INDEX

DATA INDEX (Continued)

DATA INDEX (Continued)

DIELECTRIC PARAMETERS

Dielectric parameters in the present report have the following notation:

κ', $\varepsilon'/\varepsilon_o$, dielectric constant relative to vacuum

κ'', $\varepsilon''/\varepsilon_o$, dielectric loss factor relative to vacuum

$\tan \delta$, or $\tan \delta_d$, dielectric loss tangent (dissipation factor)

κ_m', μ'/μ_o, magnetic permeability relative to vacuum

κ_m'', μ''/μ_o, magnetic loss factor

$\tan \delta_m$, magnetic loss tangent

σ, a.c. volume conductivity in mho-cm

ρ, a.c. volume resistivity in ohm-cm

MATERIALS INDEX

I. INORGANIC COMPOUNDS

Aluminum oxides

Single crystal, sapphire — Union Carbide

Sample Code M7-2054-7, 8.515 GHz, 25°C

Field direction relative to optic axis	κ'	tan δ
∥	11.60 ± .03	.00005 ± .00003
⊥	9.40 ± .02	.00007 ± .00005

Ceramic, AlSiMag 772 — American Lava

8.51[illegible] GHz, 25°C

D-c volume resistivity at 25°C > 2×10^{15} ohm-cm

$\kappa = 9.295 \pm .03$, $\tan \delta = .000073 \pm .000015$

Ceramic, high alumina — A.C. Spark Plug

T°C	ρ (ohm-cm)	T°C	ρ (ohm-cm)
25	>1.E17	500	2.25E8
60	1.E16	600	6.3E7
100	2.E15	700	1.53E7
200	1.9E12	800	3.22E6
300	4.0E10	900	6.1E5
400	2.32E9		

Breakdown voltage 60 Hz rms, .007" thickness, 1/8" diam. elect., short-time test

T°C	kV
23	8.0
137	7.0
237	6.0

Aluminum oxide mixtures

With boron nitride — Ceradyne

% Comp. Al_2O_3	w/o BN	Ceradyne No.	Density (g/cm^3)	25°C κ'	8.5 GHz tan δ
60	40	1603	2.87	6.61	.0004
70	30	1605	2.98	6.92	.00036
50	50	1597	2.603	6.01	.0026
50	50	1595	2.832	6.52	.00045

Aluminum oxide mixtures (cont.)
With silicate fibers — McDonnell Douglas

After drying for 48 hrs at 150°C
Density 1.65 g/cm^3

8.5 GHz, 25°C

κ = 2.88   tan δ = .00235

Ammonia — Matheson

Solid

	8.5 GHz		14 GHz	
T°C	κ'	tan δ	κ'	tan δ
-195	2.96	.00034	2.96	.00032
-160	2.96	.00035	2.96	.00034
-140	2.97	.00036	2.97	.00035
-130	2.98	.00037	2.98	.00037
-120	3.00	.00039	3.00	.00038
-110	3.02	.00044	3.02	.0005
-105	3.03	.00050	3.03	.0007
-100	3.04	.0020	3.03	.00132
-95	3.04	.0054	3.04	.0026
-90	3.05	.0049	3.04	.0053
-85	3.07	.0046	3.06	.0035
-80	3.14	.0047	3.12	.0025

Liquid

8.515 GHz			14.0 GHz		
T°C	κ'	κ''	T°C	κ'	κ''
-76.2	24.52	6.85	-76.5	19.24	9.57
72.6	24.44	6.81	75.	19.33	9.48
71.7	24.38	6.44	72.4	19.50	9.37
67.0	24.14	6.08	68	19.69	8.72
64.5	24.00	5.65	61.7	19.99	7.80
62.0	23.87	5.30	59.5	20.14	7.54
57.7	23.58	4.91	56.3	20.5	7.12
51.2	23.08	4.28	52.4	20.76	6.65
47.7	22.77	4.01	48.7	20.86	6.24
42.0	22.23	3.61	44.2	21.42	5.78
40.3	22.04	3.51	41.5	21.07	5.56
38.3	21.82	3.40	38.7	21.08	5.33
34.5	21.46	3.21	36.3	21.08	5.07
33.9	21.35	3.19	33.6	21.07	4.96

Beryllium oxide + silicon nitride ceramic
"Fiberlox" — National Beryllia

8.5 GHz, 25°C

κ' = 7.242   tan δ = .00235

Beryllium oxide + silicon nitride ceramic (cont.)

"Niberlox" National Beryllia

3.13 to 2.94 GHz			5.1 to 4.89 GHz		
T^oC	κ'	tan δ	T^oC	κ'	tan δ
25	7.245	.00117	25	7.21	.001
98	7.304	.00118	500	7.73	.0015
191	7.396	.00119	600	7.85	.0022
254	7.458	.00110	700	7.99	.0029
362	7.578	.00113	800	8.15	.0032
438	7.665	.00124	900	8.30	.0042
471	7.703	.00142	1000	8.47	.0049
515	7.765	.00165	1100	8.65	.0057
554	7.823	.00200	1200	8.80	.0071
592	7.872	.00245	1220	8.84	.0075
643	7.955	.00301	1250	8.88	.0083
675	8.002	.00329	1277	8.91	.0092
696	8.033	.00344	1305	8.96	.0118
735	8.106	.00375	1327	9.01	.0210
768	8.171	.0039	1335	9.02	.0035
			1343	9.05	.0037

Boron nitride, hot-pressed, grade HBC Union Carbide

Electric field ‖ pressing direction

T^oC	Freq., Hz	10^2	10^3	10^4	10^5	10^6	10^7	10^8
23	κ	4.63	4.63	4.63	4.63	4.63	4.63	4.63
	tan δ	3.6	3.2	2.7	2.5	.79	<.6	<.6
100	κ	4.68	4.65	4.64	4.64	4.64	4.64	-
	tan δ	12.7	12.9	11.1	8.2	3.7	2.	-
200	κ	4.70	4.68	4.68	4.67	4.64	4.64	-
	tan δ	29.6	25.8	20.7	14.6	6.1	2.	-
300	κ	4.90	4.81	4.75	4.71	4.71	4.72	-
	tan δ	136.	108.	66.	25.7	8.7	3.8	-
400	κ	4.99	4.88	4.81	4.76	4.74	4.72	-
	tan δ	163.5	142.5	97.	43.3	13.6	4.3	-
500	κ	5.07	5.92	4.85	4.80	4.76	4.74	-
	tan δ	266.	172.	116.	87.5	48.3	16.5	-

All values of tan δ are multiplied by 10^4.

Boron nitride, hot-pressed, grade HBC

Electric field ⊥ pressing direction

4.08 to 3.99 GHz

T°C	κ'	10^4xtan δ
25	4.142	1.4
100	4.146	1.5
200	4.154	2.5
300	4.162	3.4
400	4.172	3.8
	Overnight hot	
500	4.181	2.7
600	4.193	2.4
700	4.205	2.7
800	4.221	3.2
900	4.237	4.
1000	4.254	5.1
1100	4.271	6.5
1200	4.290	16.2
1300	4.308	24.
1350	4.317	33.3
1375	4.321	38.
1400	4.326	42.
1425	4.331	48.
1500	4.345	68.

8.515 GHz

T°C	κ'	10^4xtan δ
25	4.142	1.5
100	4.14	1.6
200	4.15	1.6
300	4.16	1.7
400	4.17	1.8
500	4.18	1.8
600	4.19	1.8
700	4.20	1.8
800	4.22	2.0

Anisotropy test on rod at 8.515 GHz, 25°C

Field direction	κ'	10^4xtan δ
E ⊥	4.150	9.4
E ∥	4.543	5.6

Potassium bromide, hot-pressed — Union Carbide

25°C, 8.515 GHz after 48 hrs. at 150°C

Sample No.	Density (g/cm³)	κ'	tan δ
15	2.10	3.573	.00006
16	2.14	3.496	.00013
17	2.43	4.320	.00094
18	2.48	4.118	.00006

Silica, Dynasil 4000 — Dynasil Corp.

8.5 to 8.6 GHz

T^oC	κ'	tan δ
25	3.825	.00016
92	3.830	.00012
189	3.836	.00010
272	3.840	.00007
337	3.844	.00006
398	3.850	.00006
544	3.864	.00007
601	3.868	.00008
700	3.880	.00012
833	3.897	.00015
862	3.904	.00016
922	3.914	.00018
997	3.925	.00020
1064	3.936	.00024
1099	3.941	.00025
1111	3.942	.00025
1181	3.956	.00027
1234	3.966	.00029
1316	3.984	.00031
1364	3.991	.00034

37.3 to 35.1 GHz

T^oC	κ'	tan δ
23	3.82±.015	.00035±.0001
195	3.84	.0003
403	3.86	.0003
610	3.87	.0002
807	3.89	.0002
1003	3.92	.0003
1205	3.95	.0003
1408	4.01	.0004
1495	4.05	.0005
1570	4.08	.0007
1650	4.14	.0010
1690	4.18	.0018
1720	4.22	.0025
1750	4.26±.04	.0038±.0004
1800	4.41*	.010*

*Extrapolated, not measured.

Silica, hot-pressed — McDonnell Douglas

8.5 GHz, 25°C

Sample		Density (g/cm^3)	κ'	tan δ
Standard Hyperpure	SC 195	1.55	2.703	.00033
	SC 103	2.07	3.604	.00004
Aggregate Hyperpure	ASC-71	1.55	2.747	<.00002
	ASC-83	1.96	3.268	.00016

Silica fiber AS-3DX 176-17 Philco-Ford

8.5 to 8.6 GHz

T°C	κ'	tan δ	T°C	κ'	tan δ
25	2.88	.00178	959	2.94	.0026
70	2.88	.00150	1001	2.94	.0030
126	2.88	.00103	1050	2.94	.0034
202	2.876	.00060	1080	2.95	.0038
300	2.88	.00035	1173	2.95	.0047
335	2.89	.00035	1223	2.97	.0053
488	2.89	.00048	1252	2.97	.0058
609	2.90	.00077	1289	2.98	.0068
680	2.91	.0010	1324	3.02	.011
799	2.93	.00155			

Silicate Glasses

Corning Glass 7052			Corning Glass 7056		
	1 GHz			1 GHz	
T°C	κ'	tan δ	T°C	κ'	tan δ
23	4.97	.0046	23	5.23	.0049
102	5.00	.0053	106	5.26	.0050
198	5.04	.0068	228	5.20	.0066
305	5.12	.0106	295	5.31	.0078
359	5.18	.0150	352	5.34	.0102
393	5.23	.0165	404	5.40	.0123
445	5.31	.0174	447	5.43	.0154
490	5.35	.0254	494	5.49	.0173
511	-	.0306	514	-	.0360
529	-	.0438	529	-	.0441
540	-	.0498	545	-	.0538
552	-	.0582	562	-	.0653
560	-	.0657	577	-	.0731
573	-	.0750	593	-	.0806
594	-	.0874	612	-	.0893
603	-	.0930	636	-	.102
622	-	.0977			
632	-	.1017			

Silicon nitride compounds — General Electric

		8.515 GHz	14 GHz	24 GHz
GE 128-2	κ'	7.72	7.71	7.67
	tan δ	.0022	.0033	.0034
	ρ (g/cm^3)	3.082	3.080	3.079
GE 129-1	κ	7.77	7.73	7.67
	tan δ	.00185	.0026	.0020
	ρ (g/cm^3)	3.087	3.089	3.080

II. MISCELLANEOUS INORGANICS

Hercynite ($FeAl_2O_4$) in air — M.I.T. Materials Science

T^oC	Freq., Hz	κ'	σ	T^oC	Freq., Hz	σ
28	1.E5	18±2	5.8E-8	527	100	1.1E-4
61	↓		7.2E-8	686	100	8.2E-4
101	↓		9.8E-8	686	1.E5	8.2E-4
170	↓		2.0E-7	718	↓	1.07E-3
221	↓		4.2E-7	778	↓	2.09E-3
260	↓		8.3E-7	829	↓	2.96E-3
299	↓		1.7E-6	836	1.E6	3.79E-3
324	↓		2.9E-6	885	↓	8.8E-3
421	↓		2.1E-5	905	↓	1.14E-2
537	↓		1.2E-4	971	↓	1.68E-2

Sand — M.I.T., Research Laboratory for Electronics

	Freq.,GHz	.3	1	3	8.5	14	24
.2% H_2O	κ'	2.95	2.93	2.91	2.90	2.89	2.86
	κ"	.0196	.017	.018	.0091	.0096	.0158
3% H_2O	κ'	3.68	3.58	3.52	.50	3.48	3.46
	κ"	.273	.122	.136	.36	.47	.48
5% H_2O	κ'	5.07	4.90	3.53	4.85	4.50	4.24
	κ"	.355	.220	.352	.630	.89	.935
8% H_2O	κ'	6.57	6.46	6.27	6.06	5.54	5.30
	κ"	.493	.309	.462	1.18	1.53	3.1
11% H_2O	κ'	8.6	8.45	8.24	8.18	7.8	6.99
	κ"	.785	.43	.691	1.89	2.42	2.60
20% H_2O	κ'	15.2	15.1	14.8	13.8	12.4	11.0
	κ"	1.15	.66	1.55	3.94	5.90	5.4

Uranium oxide (UO_3) powder General Electric

	.915 GHz			2.45 GHz	
T°C	κ'	tan δ	T°C	κ'	tan δ
23	4.27	.00067	23	4.27	.00058
93	4.26	.00092	98	4.27	.00115
272	4.26	.00550	264	4.26	.00292
345	4.28	.00783	359	4.27	.0053
482	4.32	.0106	456	4.28	.0071
517	4.35	.0125	517	4.32	.0101

Chalcopyrite ($CuFeS_2$) powders Kennecott Copper

Sample	Freq.	1 GHz	3 GHz	8.5 GHz
Course	κ'	10.38	9.07	7.37
Messina	κ''	2.32	2.09	2.49
-16 + 20 mesh	tan δ	.223	.221	.338
	σ	1.29E-3	3.48E-3	1.18E-2
	α	.64	1.88	6.83
Fine	κ'	10.07	6.61	5.83
UCD	κ''	.745	.32	.186
-120 mesh	tan δ	.074	.0484	.0319
	σ	4.14E-4	5.33E-4	8.8E-4
	α	.213	.339	.596

The conductivity (σ) is expressed in reciprocal ohm-cm. The absorption coefficient (α) is in db/cm.

Supramica 1100 Mycalex

T°C	Freq., Hz	10^2	10^3	10^4	10^5	10^6	10^7	10^8	10^9	8.5E9	1.4E10	2.4E10
25	κ'	6.95	6.92	6.89	6.85	6.82	6.80	6.77	7.52	7.48	7.46	7.62
	tan δ	.00588	.00365	.00318	.00232	.00175	.00133	.0021	.0031	.00413	.0048	.0056
100	κ'	7.22	7.04	6.97	6.94	6.90	6.88		7.54	7.49	7.48	7.44
	tan δ	.0300	.0119	.0065	.0051	.0039	.0027		.0037	.00470	.0054	.0060
200	κ'	9.31	7.83	7.47	7.16	6.97	6.96		7.50	7.51	7.52	7.47
	tan δ	.254	.109	.0293	.0159	.00874	.00643		.0051	.00490	.0064	.0071
300	κ'	26.0	14.04	9.84	7.74	7.30	7.05		7.64	7.60	7.58	7.53
	tan δ	.972	.483	.221	.092	.0345	.0159		.0092	.00681	.0080	.0091
400	κ'					9.20	7.49		7.82	7.89	7.67	7.82
	tan δ					.1556	.0159		.0195	.0106	.0122	.0131
450	κ'								7.92	7.80	7.76	7.71
	tan δ								.014	.0146	.0151	.0166
500	κ'					13.89	9.41		8.05	7.93	7.91	7.84
	tan δ					.472	.242		.0255	.0201	.0211	.0233
540	κ'					18.6	11.3		8.37	8.15	8.08	7.98
	tan δ					.67	.343		.040	.0315	.0339	.034

In frequency range 10^2 to 10^8 electric field is perpendicular to sheet stack; at higher frequencies field is parallel.

III. ORGANICS

Epoxy compound — Allied Resin

T°C	Freq., Hz	10^2	10^3	10^4	10^5	10^6
25	κ'	4.12	4.046	4.009	3.933	3.856
	tan δ	.0177	.0111	.0105	.01295	.0152
100	κ	4.85	4.518	4.354	4.244	4.125
	tan δ	.0779	.0448	.0258	.0202	.0189

Black FM Film — American Cyanamid

T°C	Freq., GHz	1	3	8.5
25	κ'	7.24	6.45	6.06
	tan δ	.202	.155	.115

"Teflon"-coated membrane — American Durafilm

25°C, 3 GHz

κ' = 3.54 tan δ = .0071

"Torlon" 2000 — Amoco

24 GHz, 25°C

	κ'	tan δ
40% Rel. Hum.	3.605	.0143
Wet	3.97	.0327

"Torlon" 4000 — Amoco

24 GHz, 25°C

	κ'	tan δ
40% Rel. Hum.	3.524	.014
Wet	3.77	.0282

"Torlon" 4000/Astroquartz — Amoco (Whittaker)

24 GHz

T°C	κ'	tan δ	T°C	κ'	tan δ
23	3.70	.0061	220	3.73	.0097
66	3.72	.0065	260	3 52	.0142
119	3.73	.0072	119	3.47	.0076
177	3.74	.0082			

"Torlon" 4103 — Amoco

8.5 GHz, 25°C

$\kappa' = 3.605$ $\tan\delta = .0120$

"Torlon" 4203 — Amoco

8.5 GHz, 25°C

$\kappa' = 3.776$ $\tan\delta = .0117$

Fluorglass laminate — Atlantic Laminates

1.3 GHz, 25°C

$\kappa' = 2.515$ $\tan\delta = .00138$

Absorber — AVCO

1 GHz

$T\,^\circ C$	$\varepsilon'/\varepsilon_o$	$\tan\delta_d$	μ'/μ_o	$\tan\delta_m$	Attenuation (db/cm)
-30	6.99	.093	2.38	.949	3.61
-20	7.06	.101	2.37	.979	3.75
-10	7.14	.116	2.36	1.01	3.91
0	7.23	.129	2.36	1.04	4.08
10	7.34	.144	2.35	1.09	4.31
20	7.46	.160	2.35	1.15	4.58
25	7.53	.169	2.34	1.165	4.69
30	7.60	.179	2.31	1.184	4.78
40	7.74	.198	2.19	1.22	4.89
50	7.83	.217	2.11	1.25	4.99

Vinyl film 133-24413-L — Borden

18 MHz

$T\,^\circ C$	κ'	$\tan\delta$	$T\,^\circ C$	κ'	$\tan\delta$
32.5	2.915	.0496	115.7	4.969	.251
37.5	2.963	.0568	125	5.364	.238
46.9	3.064	.0733	129	5.599	.228
54.5	3.063	.0968	134.2	5.799	.228
66.4	3.328	.130	140.4	6.046	.191
75.7	3.620	.1566	152.2	6.317	.148
81.5	3.748	.182	156	6.423	.133
91.5	3.988	.214	159.5	6.497	.121
99.9	4.302	.237	163.5	6.546	.110
108	4.618	.248			

Adhesive, HA5164 XLS-101 — Borden

100 MHz

$T\,^\circ C$	κ'	$\tan\delta$	$T\,^\circ F$	κ'	$\tan\delta$
79	2.41	.0195	188	2.69	.0666
89	2.42	.0223	218	2.80	.0671
113	2.47	.0327	255	2.86	.0607
150	2.54	.0511	275	2.90	.0481

"Astral" 360 polyaryl — Carborundum

8.5 GHz, 25°C

$\kappa' = 3.454$ $\tan\delta = .01215$

"Ekkcel" I 200 copolyester — Carborundum

8.5 GHz, 25°C

	κ'	$\tan\delta$
Piece 1	3.158-3.183	.00358-.00362
Piece 2	3.268-3.297	.00367-.00289

Polyimide film — Carborundum

T°C	Freq.	d.c.	100 Hz	1 kHz	10 kHz	100 kHz	1 MHz
25*	κ'		3.50	3.49	3.48	3.44	3.27
	$\tan\delta$		.00203	.00276	.00541	.00883	.00854
	ρ	>1.E18					
100	κ'		2.99	2.99	2.98	2.973	2.93
	$\tan\delta$		.00220	.00179	.00221	.00190	.0011
	ρ	6±3E16					
25	κ'		2.99	2.99	2.98	2.98	2.94
	$\tan\delta$		.00202	.00109	.00125	.00144	.00109
	ρ	>1.E18	2.98E12				
-75	κ'		2.98	2.98	2.98	2.97	2.94
	$\tan\delta$		.00012	.00096	.00126	.00129	.00203
	ρ	>1.E18					
200	κ'		2.89	2.86	2.84	2.82	2.78
	$\tan\delta$		.0147	.00729	.00382	.00210	.00135
	ρ	4.3E11	4.21E11				
235†	ρ	5.E9					
257†	ρ	5.E8					
260	ρ	2.2E8					
256	κ'		38.8	6.46	2.89	2.64	2.56
	$\tan\delta$		8.24	5.74	2.05	.141	.0145
	ρ		5.63E8	4.85E8			
282†	κ'			10.85			
	$\tan\delta$			8.30			
	ρ			2.0E7			
300	κ'		5.22	9.93	3.36	2.62	2.50
	$\tan\delta$		30.15	15.4	5.49	.777	.0925
	ρ	1.03E7	1.14E7	1.18E7			

* As received condition; for all other data sample was in dry N_2 after heating to 150°C.

† Not in thermal equilibrium.

Epoxy/Glass laminate Fortin "No Flow"

"B" stage pressed into "C" stage — Collins Radio

	E ⊥ to sheet, 1 MHz		10 MHz			E ∥ to sheet, 1 GHz		3 GHz	
T^oC	κ'	tan δ	κ'	tan δ	T^oC	κ'	tan δ	κ'	tan δ
-55	3.94	.0156	3.73	.0139	-55	3.73	.0058	3.71	.0105
-40	4.00	.0182	3.76	.0162	-40	3.74	.0097	3.72	.0126
-20	4.11	.0223	3.87	.0212	-20	3.75	.0153	3.73	.0156
0	4.23	.0259	3.97	.0271	0	3.77	.0212	3.74	.0206
10	4.30	.0267	4.03	.0300	25	3.82	.0295	3.78	.0278
23.8	4.43	.0280	4.14	.0336	40	3.87	.0346	3.83	.0323
40	4.60	.0258	4.29	.0370	60	3.94	.041	3.88	.0390
60	4.84	.0239	4.51	.0349	80	4.06	.049	3.97	.047
80	5.07	.0227	4.72	.0330	100	4.19	.058	4.08	.0552
100	5.28	.0275	4.87	.0345	120	4.32	.064	4.21	.0636
115	5.42	.0380	5.01	.0387	125	4.39	.067	4.25	.0658
125	5.57	.0452	5.08	.0426					

	100 MHz	
	κ'	tan δ
25	4.02	.0339

E ∥ to sheet, 8.5 GHz

T^oC	κ'	tan δ	T^oC	κ'	tan δ
-55.5	3.699	.0155	106.0	4.044	.0617
-44.	3.697	.0173	117	4.089	.0650
-32.1	3.699	.0221	125	4.142	.0673
-21	3.697	.0255	1304	4.184	.0686
- 5.4	3.723	.0294	77	3.912	.0508
14.5	3.723	.0294	62	3.855	.0443
31.5	3.757	.0323	232	3.745	.0304
95.1	4.010	.0581			

Epoxy/Glass laminate Mica "No Flow" 102-68

Pre-preg. pressed into "C" stage — Collins Radio

E ⊥ to sheet

	1 MHz		10 MHz			1 MHz		10 MHz	
T^oC	κ'	tan δ	κ'	tan δ	T^oC	κ'	tan δ	κ'	tan δ
-55	3.96	.0187	3.93	.0160	50	4.71	.0253	4.48	.0366
-40	4.03	.0225	4.00	.0211	60	4.80	.0242	4.57	.0364
-30	4.10	.0251	4.04	.0225	70	4.89	.0239	4.65	.0360
-20	4.15	.0271	4.08	.0261	80	4.98	.0253	4.75	.0370
-10	4.22	.0284	4.10	.0297	90	5.06	.0277	4.84	.0385
0	4.29	.0292	4.14	.0301	100	5.17	.0309	4.96	.0403
10	4.36	.0202	4.18	.0322	110	5.29	.0371	5.08	.0423
20	4.43	.0288	4.22	.0339	115	-	-	5.15	.0435
25	4.49	.0285	4.26	.0345	120	5.41	.0461	5.08	.0469
30	4.53	.0280	4.31	.0350	125	5.48	.0509	5.00	.0510
40	4.62	.0266	4.38	.0359					

Epoxy/Glass laminate Mica "No Flow" 102-68

Pre-preg. pressed into "C" stage — Collins Radio

E ∥ to sheet

	1 GHz		3 GHz	
$T^{o}C$	κ'	tan δ	κ'	tan δ
-55	3.65	.0093	3.63	.0094
-40	3.69	.0125	3.65	.0115
-30	3.72	.0149	3.67	.0132
-20	3.75	.0174	3.69	.0153
-10	3.77	.0198	3.71	.0175
0	3.79	.0222	3.73	.0200
10	3.81	.0244	3.75	.0228
25	3.86	.0279	3.785	.0269
40	3.89	.0316	3.82	.0313
50	3.93	.0342	3.855	.0340
60	3.99	.0373	3.89	.0384
70	4.05	.0413	3.93	.0425
80	4.14	.0454	3.985	.0468
90	4.23	.0467	4.05	.0515
100	4.33	.0538	4.10	.0560
110	4.42	.0574	4.15	.0605
120	4.52	.0604	4.21	.0648
125	4.55	.0624	4.23	.0665

	8.5 GHz	
$T^{o}C$	κ'	tan δ
-55	3.639	.0117
-40	3.653	.0130
-30	3.665	.0142
-20	3.684	.0161
-10	3.704	.0182
0	3.721	.0202
10	3.740	.0225
20	3.756	.0249
25	3.765	.0262
30	3.773	.0276
40	3.782	.0292
50	3.796	.0325
60	3.839	.0378
70	3.894	.0449
80	3.959	.0530
90	4.032	.0594
100	4.072	.0649
110	4.079	.0667
115	-	-
120	4.076	.0691
125	4.082	.0710

Custom Poly-"Teflon" fiberglas — Custom Materials

1.3 GHz, 25°C

κ = 2.544 tan δ = .00125

Thymol — Eastman

Solid, 45°C

Freq., Hz	κ'	κ"	σ
3	16.44	31.6	5.85E-11
10	5.09	12.8	7.11E-11
31	4.14	5.12	3.79E-11
98	3.45	2.14	1.17E-10
996	2.72	.401	2.22E-10
9987	2.61	.0570	3.16E-10
$1x10^5$	2.62	.00575	3.19E-10
$1x10^6$	2.61	.00104	5.80E-10
$9.5x10^6$	2.61	.00134	7.07E-9
$1.8x10^7$	2.61	.00234	2.34E-8

Solid, 25°C

Freq., Hz	κ'	κ"
$1.5x10^8$	2.45-2.52	.0070
$3x10^8$		.0110
$5x10^8$		.0098
$1x10^9$		.0070
$1.5x10^9$		.0055
$2.45x10^9$		.0054
$3x10^9$		.0062
$4.9x10^9$		.0104
$8.5x10^9$	2.45	.00546
$1.4x10^{10}$	2.45	.0146
$2.4x10^{10}$	2.45	.030

Thymol (cont.) Eastman

Liquid, 52°C

Freq., Hz	$\kappa'_{meas.}$	κ'_{fit} *)	$\kappa''_{meas.}$	κ''_{fit} *)
10^2	4.61	4.52	4.94	4.94
10^3	4.52	↓	.494	.494
10^4	4.50		.0494	.0494
10^5	4.50		.00512	.00502
10^6	4.50		.00157	.00127
9.5×10^6	4.50		.0105	.0074
1.8×10^7	4.50		.0200	.0139
1.5×10^8	4.49	4.51	.136	.115
3×10^8	4.48	4.49	.257	.228
5×10^8	4.46	4.44	.369	.369
1×10^9	4.20	4.24	.650	.652
1.5×10^9	3.95	3.99	.727	.819
2.45×10^9	3.73	3.58	.911	.898
3×10^9	3.49	3.40	.804	.872
5×10^9	3.25	3.04	.675	.689
8.5×10^9	2.96	2.84	.510	.458
1.4×10^{10}	2.83	2.77	.392	.291
2.4×10^{10}	2.72	2.74	.359	.173

*Computer best fit results to parameters of a single relaxator plus conductance: $\kappa_\infty = 2.721$, $\sigma = 2.75E-10$, $\kappa_s - \kappa_\infty = 1.799$; critical frequency 2.33E9, tau = 6.83E-9 sec.

Silicone rubber absorbers Emerson & Cuming

Sample	Freq., Hz	10^5	10^6	10^7	3×10^7	10^8 *	1.5×10^8	3×10^8	1×10^9	3×10^9
FGM 125	ϵ'/ϵ_0	8.78	7.95	7.60	7.52	7.39	7.37	7.32	7.25	7.20
	$\tan\delta_d$	.190	.052	.021	.019	.016	.015	.013	.011	.007
	μ'/μ_0			12.0	11.8	9.2	8.4	7.00	3.32	1.22
	$\tan\delta_m$			.04	.06	.27	.332	.500	1.06	1.74
CDS	ϵ'/ϵ_0	12.4							12.55	12.3
	$\tan\delta_d$	.0046	.0041	.0044	.0044	.0046	.0047	.0049	.0061	.0113
	μ'/μ_0			[illegible]	4±1	[illegible]	3.70	3.70	3.53	2.82
	$\tan\delta_m$			<.1	<.1	.025	.036	.0614	.192	.415
FGM 40	ϵ'/ϵ_0	31.8	31.7	31.6				31.5	31.5	31.7
	$\tan\delta_d$	.037	.018	.013	.012	.0088	.0082	.0085	.0083	.0109
	μ'/μ_0			7.8	7.8	7.8	7.8	7.7	7.44	5.41
	$\tan\delta_m$			<.06	<.07	.04	.059	.110	.605	.785
FDS	ϵ'/ϵ_0	7.40	6.85	6.60	6.50	6.41	6.37	6.35	6.20	6.11
	$\tan\delta_d$	.005	.0233	.0117	.0101	.010	.010	.0104	.0114	.0145
	μ'/μ_0			6.5	6.5	5.4	5.16	4.44	2.76	1.325
	$\tan\delta_m$			<.05	<.05	.18	.316	.336	.713	.1086

*Interpolated values, not measured.

Carbon foam absorber — Emerson & Cuming

EHD-18-F, 25°C

Freq., GHz	κ'	κ"
1	3.16	2.43
3	2.55	1.17
8.5	1.90	.68
14	1.75	.34

Laminates — Glastic Corp.

1 GHz, 25°C

	κ'	tan δ
Glastic G-200, buff (nearly NEMA G-10)	5.07	.0192
Glastic TSF, brown (NEMA GPO-2)	4.97	.0142
Glastic UTR, red (NEMA GPO-1)	4.38	.0145

Molded polyvinyl chloride — Grace

Grace 252
30 MHz, density 1.41 g/cm^3

T°C	κ'	κ"	tan δ	σ	T°C	κ'	κ"	tan δ	σ
21.0	3.032	.0288	.0095	4.81E-7	116.7	3.331	.333	.100	5.56E-6
29.5	3.054	.0299	.0098	5.0E-7	129.5	3.429	.462	.135	7.71E-6
39.3	3.055	.0470	.0154	7.85E-7	138.7	3.601	.751	.209	1.25E-5
66.0	3.076	.0504	.0164	8.41E-7	146.9	3.870	.986	.254	1.646E-5
73.7	3.106	.0666	.0214	1.11E-6	160.9	4.297	1.39	.323	2.32E-5
89.9	3.127	.0980	.0313	1.64E-6	175.5	4.673	1.615	.346	2.70E-5
104.7	3.252	.1816	.0558	3.03E-6	180.5	4.906	1.667	.340	2.78E-5

Molded co-polymer of polyvinyl chloride — Grace

Grace EM 134, 30 MHz, density 1.35 g/cm^3

T°C	κ'	κ"	tan δ	σ	T°C	κ'	κ"	tan δ	σ
21.1	2.891	.054	.018	8.91E-7	121.0	3.229	.398	.123	6.64E-6
32.5	2.899	.035	.012	5.8E-7	129.3	3.326	.505	.152	8.42E-6
41.5	2.908	.0387	.013	6.5E-7	138.3	3.55	.674	.190	1.12E-5
59.9	2.932	.0553	.0189	9.2E-7	142.9	3.66	.825	.226	1.38E-5
64.9	2.940	.058	.0198	9.7E-7	147.6	3.832	.945	.247	1.58E-5
71.3	2.973	.0694	.0234	1.16E-6	163.7	4.48	1.49	.332	2.49E-5
82.9	3.007	.0903	.0300	1.51E-6	166.3	4.62	1.52	.328	2.53E-5
95.5	3.040	.129	.0426	2.17E-6	170.0	4.78	1.62	.338	2.71E-5
111.1	3.134	.272	.0866	4.53E-6	175.0	5.06	1.73	.341	2.89E-5

Dioctalphalate, Hactol 101 — Hatco

Liquid, 25°C

	1 GHz	3 GHz	8.5 GHz
κ'	2.74	2.645	2.59
tan δ	.109	.0635	.0438

Niax polyol, 10 ring 130, liquid — MIT, Mech. Eng. Dept.

T°F	Freq., kHz	κ'	σ
76.4	1	8.80	9.08E-9
87.4	1	-	1.255E-8
93.7	1	-	1.47E-8
105.2	1	-	1.90E-8
108.5	10	7.94	2.31E-8
125.2	10	-	3.03E-8
134.8	10	-	3.29E-8
141.5	10	7.81	3.40E-8
149.7	10	-	3.50E-8
159.7	10	-	3.49E-8

Niax polyol W137D408, liquid, clear — MIT, Mech. Eng. Dept.

T°C	Freq., kHz	κ'	σ
74	1	9.85	3.45E-8
74	10	8.37	3.76E-8
74	100	7.96	5.09E-8
88.5	1	-	4.65E-8
106.5	1	-	6.32E-8
127.2	1	-	7.89E-8
141.2	1	-	8.74E-8
152.9	10	-	9.43E-8
167.1	10	-	9.55E-8
171.4	10	-	9.61E-8

Same, with carbon

	Freq., Hz	κ'	σ
75	1	10.8	3.82E-8
90.5	1	-	6.18E-8
96	1	-	7.08E-8
101	1	-	7.84E-8
105	10	9.12	8.55E-8
114.8	10	-	1.04E-7
123	10	-	1.20E-7
130.4	10	-	1.32E-7
140.5	10	-	1.48E-7
147.5	10	-	1.57E-7
154	10	-	1.65E-7
167	10	-	1.80E-7
170.9	10	-	1.86E-7

Isocyanate, SF-52, liquid — MIT, Mech. Eng. Dept.

T°F	κ'	σ
83.7	14.7	2.49E-9
96	-	6.28E-9
105	-	8.50E-9
109	-	9.60E-9
122	-	1.25E-8
126	-	1.40E-8
132.7	-	1.58E-8
135	-	1.64E-8
142.7	-	1.86E-8
148.5	-	2.16E-8
153.2	-	2.39E-8
159.2	-	2.74E-8
164.5	-	3.25E-8
168.7	-	3.51E-8
170	11.9	3.85E-8

Chlorinated polypropylene — MIT Mech. Eng.

22% total chlorination on surface of pellets about 2 mm diam., compacted sample (#38-1)

18 MHz

T^oC	κ'	κ''	σ	T^oC	κ'	κ''	σ
20	2.58	.0245	2.45E-7	125	2.39	.0360	3.61E-7
35	2.62	.0252	2.52E-7	133	2.37	.0324	3.24E-7
49	2.62	.0351	3.51E-7	138	2.36	.0322	3.23E-7
63	2.60	.0414	4.15E-7	142	2.36	.0325	3.25E-7
79	2.55	.0440	4.41E-7	148	2.49	.0291	2.92E-7
92	2.49	.0428	4.29E-7	152	2.51	.0306	3.06E-7
100	2.47	.0421	4.22E-7	159	2.55	.0295	2.96E-7
115	2.40	.0376	3.76E-7				

For additional data on chlorinated polyolefins see Ph.D. Thesis of Lewis Erwin, Mechanical Engineering Department, MIT, 1976.

"Teflon"-fused quartz laminate — Philco-Ford (Lincoln Lab.)

8.515 GHz, 23°C

$\kappa' = 2.35$ $\tan\delta = .00052$

"Rytron" R4, polyphenylene sulfide — Phillips Petroleum

8.515 GHz, 25°C

$\kappa' = 4.01$ $\tan\delta = .0052$

"Tafzel," 20% glass reinforced — RCA

At 25°C

Freq., Hz	60	1E3	1E6	1E9	3E9	1E10
κ'	2.98	2.97	2.96	2.94	2.93	2.92
$\tan\delta$	.0018	.0021	.0057	.0175	.016	.0142

15% TFE, polyphenylene sulfide

κ'	3.01	3.00	2.99	2.99	2.99	2.98
$\tan\delta$	.00062	.00090	.00064	.0018	.00365	.0055

15% TFE, polysulfone

κ'	2.96	2.92	2.88	2.85	2.84	2.83
$\tan\delta$	.0022	.0011	.0042	.0044	.0053	.0062

Solithane No. 1 — Thiokol

1 GHz, 25°C

$\kappa' = 2.632$ $\tan\delta = .0244$

Composition B U.S. Army

915 MHz			2450 MHz		
T^oF	κ'	tan δ	T^oF	κ'	tan δ
80.8	2.832	.00273	81.5	2.779	.00191
84.8	2.829	.00298	84.7	2.781	.00218
89.2	2.830	.00363	88.6	2.780	.00251
97.1	2.831	.00408	97.0	2.781	.00296
109.5	2.833	.00496	109.5	2.784	.00357
121.3	2.834	.00563	121.5	2.783	.00426
133	2.836	.00640	133	2.780	.00491
146.7	2.841	.00740	146.8	2.784	.00601
158.2	2.855	.00895	158.9	2.791	.00744
159.4	2.857	.0092	159.5	2.806	.00788
160.8	2.868	.0097	159.5	2.808	.00805
161.9	2.871	.0098	160.6	2.848	.0084
167.2	2.915	.0131	161.9	2.855	.0088
170.2	2.945	.0153	164.2	2.864	.0095
170.2	2.948	.0158	166.7	2.871	.0107
170.2	2.949	.0162	167.2	2.875	.0108
170.2	2.951	.0167	170.2	2.905	.0143

Minol A

915 MHz			2450 MHz	
T^oF	κ'	tan δ	κ'	tan δ
80.1	6.26	.0280	5.52	.0316
89.3	6.27	.0283	5.52	.0320
97.7	6.29	.0291	5.53	.0324
107.2	6.30	.0304	5.54	.0333
116.6	6.30	.0316	5.54	.0336
125.9	6.35	.0327	5.57	.0343
135.6	7.03	.0346	6.07	.0408
144.4	7.09	.0366	6.11	.0424
153.4	7.14	.0386	6.14	.0449
162.6	7.19	.0405	6.18	.0468
167.2	7.21	.0422	6.20	.0481
171.9	7.26	.0442	6.23	.0507
176.4	7.66	.0599	6.56	.0767
181.4	8.27	.107	∿7.10	∿.116

"Tritonal," H_2O contaminated, 915 MHz

T^oF	κ'	tan δ	T^oF	κ'	tan δ
77.6	5.51	.0355	146.3	5.28	.0551
83.4	5.51	.0370	155	5.30	.0570
91.4	5.48	.0390	159.7	5.36	.0582
101.4	5.46	.0407	163.8	5.45	.0606
110.3	5.43	.0433	131.7	5.33	.0524
119.1	5.38	.0464	110	5.29	.0461
128	5.33	.0481	89.7	5.26	.0399
135.9	5.29	.0511			

"Tritonal" at 2450 MHz U.S. Army

T°F	κ'	tan δ	T°F	κ'	tan δ
82.3	4.99	.0175	155.6	5.04	.0313
91.3	4.97	.0187	161.4	5.05	.0317
100.4	4.97	.0194	164.6	5.05	.0332
109.7	4.96	.0204	168.6	5.06	.0335
118.7	4.95	.0218	173.5	5.09	.0356
123.4	4.94	.0225	177.8	4.16	.0544
127.8	4.95	.0239	177.8	4.03	.0569
132.4	4.94	.0242	180.1	2.65	.140
141.7	4.99	.0277	180.1	2.61	.148
151.2	5.01	.0297			

TNT, trinitrotoluene U.S. Army

915 MHz			2450 MHz		
T°F	κ'	tan δ	T°F	κ'	tan δ
83.4	3.123	.00212	83.4	3.102	.00183
97	3.127	.00282	97	3.104	.00214
107.5	3.132	.00316	107.5	3.108	.00234
120.4	3.135	.00360	120.4	3.111	.00253
129.3	3.137	.00366	129.3	3.112	.00272
138.6	3.140	.00400	138.6	3.113	.00295
145.1	3.141	.00449	145.1	3.112	.00328
152.2	3.142	.00523	152.2	3.115	.00376
156.8	3.150	.00597	156.8	3.123	.00443
161.4	3.157	.00736	161.4	3.125	.00496
163.8	3.168	.00919	163.8	3.130	.00697
166.4	3.181	.0117	166.4	3.137	.00898
169	3.209	.0172	169	3.153	.0128
170.8	3.231	.0214	170.8	3.167	.0165
173.6	3.319	.0374	173.6	3.204	.0218
178.4	3.645	.0937	173.6	3.210	.0255
180.6	3.677	.0973	173.6	3.221	.0296
			178.4	3.370	.0639
			180.6	3.382	.0709

U.C. 8950-24-3 Union Carbide (Whittaker)

24 GHz

		κ'	tan δ
22°C	Ambient	3.145	.0083
24°C	Wet	3.26	.0165

Ferro/Kerimid 581 Astroquartz Whittaker

28% resin wt., 1.8% voids
Measured at 8.5 GHz, water soaked, after 24-hour boil

T°F	κ'	tan δ	T°F	κ'	tan δ
73	3.627	.0093	400	3.587	.0078
206	3.661	.0087	500	3.532	.00764
300	3.650	.0083			

Ferro/Kerimid E glass

26% resin wt. .3% voids | Whittaker

Measured at 8.5 GHz, water soaked after 24 hour boil

T^oF	κ'	tan δ	T^oF	κ'	tan δ
64	5.145	.0107	398	5.195	.0112
200	5.212	.0109	499	5.242	.0106
300	5.218	.0109			

Hexcel F-178/E glass | Whittaker

42% resin wt., 2% voids

Measured at 8.5 GHz, water soaked after 24-hour boil

T^oF	κ'	tan δ	T^oF	κ'	tan δ
73	4.454	.0150	400	4.524	.0218
200	4.504	.0167	498	4.323	.0214
300	4.512	.0185			

Hexcel F178/Astroquartz 581 | Whittaker

34.4 to 37.4% resin wt., 0.6 to 1.6% voids

T^oF	κ'	tan δ	T^oF	κ'	tan δ
75	3.572	.0148	400	3.558	.0210
199	3.622	.0167	500	3.441	.0222
261	3.601	.0165	75	3.385	.0064
310	3.533	.0190			

Experimental P1/Quartz | Whittaker

Brunswick-BP1 373581 Astroquartz

Measured water soaked after 24-hour boil

	8.5 GHz			24 GHz		
	T^oF	κ'	tan δ	T^oF	κ'	tan δ
	71	4.498	.0714	73	3.86	.0924
	200	4.491	.0330	147	4.09	.0725
	300	3.835	.0228	248	3.65	.0228
5 min.,	300	3.740	.02005	345	3.42	.0087
	400	3.341	.0133	432	3.37	.0118
	500	3.237	.02216	500	3.36	.0130
	75	3.349	.0040	73	3.35	.0045

PD 753/Astroquartz A 172 | Whittaker

24 GHz, dry

T^oF	κ'	tan δ	T^oF	κ'	tan δ
23	3.16	.00227	177	3.205	.00242
66	3.17	.00258	221	3.213	.00261
121	3.19	.00295	260	3.23	.00292

PD 753/Astroquartz A172 Whittaker

24 GHz, water soaked after 24-hour boil

T°F	κ'	tan δ	T°F	κ'	tan δ
73	3.093	.01154	428	2.92	.0037
163	3.08	.0048	502	2.90	.0033
250	3.04	.0047	79	3.07	.0027
351	2.99	.0053			

Skybond 710/Astroquartz 581 Whittaker

21% resin wt., 9.4% voids
8.5 GHz, water soaked after 24-hour boil

T°F	κ'	tan δ	T°F	κ'	tan δ
69	8.83	.2097	300	3.190	.0248
200	7.219	.0573	398	3.035	.0070
200, 1 min.	7.152	.0638	500	2.909	.0072
200, 2 min.	6.972	.0632	76	3.151	.0024

MATERIALS AND COMPANY INDEX*

* In this index Roman numerals refer to <u>Tables of Dielectric Materials</u>, Vols. IV, V, and VI. P.R. refers to Tech. Rep. AFML-TR-72-39. Arabic number 8 refers to Tech. Rep. AFML-TR-74-250, Pt. II. This report is referenced by Arabic number 9 followed by page numbers.

*U.S. Government Printing Office: 1977 — 787-001/65